PLENARY SESSION 2
Issues in LCA and Carbon/Water Footprinting

Estimating the greenhouse gas footprint of Knorr products

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ABSTRACT

A meta-product approach was used to assess the life cycle GHG footprint of Knorr product groups; these meta-product GHG footprints were then aggregated with the production volumes to obtain Knorr's global footprint. The variability introduced with the model simplification was propagated through the model in order to enhance the robustness of the results, which proved useful for the intended applications: understanding the sources of emissions; suggesting opportunities for improvement; estimating the impact of innovations on the brand's impacts; and setting and monitoring targets.

Keywords: greenhouse gas (GHG) footprint; Knorr; meta-product; soups; bouillons

1. Introduction

Knorr is one of the world's largest food brands, and the largest Unilever brand, with a presence in ca. 90 countries. Its product portfolio includes dry and wet soups, bouillons and sauces, fruit and vegetable shot drinks as well as frozen meals and 'meal-makers' (i.e. seasoning mixes for specific dishes, e.g. stir fries, stews, casseroles etc). Knorr product supply chains are truly global with many thousands of ingredients sourced from around the world. This paper describes an approach to calculate the annualized greenhouse gas (GHG) footprint of the total product portfolio of the Knorr brand and its main product types. The issue of GHG emissions has been identified as one of Unilever's priority environmental impact themes alongside water, waste and sustainable sourcing: this assessment was therefore conducted to help the Knorr brand:

1. Measure and understand the GHG emissions related to its product portfolio
2. Identify opportunities to manage GHG emissions in the Unilever-owned operations (manufacture) and influence managed reductions elsewhere in the Knorr product lifecycles
3. Assess the impact of the brand's innovation strategy on its GHG footprint.

Unilever routinely measures and reduces in-house GHG emissions from energy per tonne of production (with a 41% reduction of GHG emissions in manufacture between 1995 and 2009, Unilever 2010); however, this is estimated to represent only 1-2% of the overall emissions caused by Unilever products along their life cycle (Unilever, 2010). Thus, the main opportunities for improvement lie upstream / downstream from the factories. We need to measure and understand such impacts in order to manage them, which requires a product (life cycle) perspective. Unilever is investing significantly in this type of activity as part of a new

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vision to double the size of the business while reducing its overall environmental impact across the entire value chain (Unilever, 2010).

2. Materials and Methods

2.1. Meta-product approach

Knorr's product portfolio includes over 7,500 different 'stock keeping units' (SKU: product/packs reflecting individual recipes, pack sizes and formats); this complexity made a bottom-up, conventional product-based carbon footprint approach impractical. A "meta-product" approach was thus developed whereby "product types" which are representative[1] of the Knorr portfolio (e.g. dry soup – instant; dry soup – cook up; wet soup – can; wet soup – aseptic…) were adopted. Meta-product is used here to refer to an abstraction of a product group that describes that product group; e.g. we define a meta-product called "dry soup – instant" which does not exist in the market, but is a good enough representation of the hundreds of variants of instant dry soups in the market. The production impact for each meta-product was derived from the dominant production technology and average recipe composition (derived as a weighted average of the 10 top-seller SKU recipes for each product type). Meta-products were defined for each region in which Knorr products are marketed (e.g. Europe, North America, Latin America…). The global Knorr Carbon Footprint was derived by multiplying the GHG impact calculated per tonne of each meta-product with the regional sales volumes in 2007.

2.2. Life Cycle Stages Modelling

Ingredients and processes considered as similar were aggregated in 'building blocks' (e.g. 'dairy products' instead of milk; cream; etc.; 'drying' instead of air drying; spray drying; drum drying; etc.). Most data on ingredients production and processing were sourced from the literature (167 references used), although primary data for some (e.g. flavours; taste enhancers; juicing and concentration…) were sourced directly from suppliers. Data on the manufacture of the final products were obtained directly from Unilever production sites for each of the technologies involved (dehydrated soups; aseptic; retorted; tunnel pasteurized; hot fill and hold; pasty bouillons; dry pressed bouillons; granulated bouillons). Product use at home was modelled according to the instructions on the product label.

2.3. Variability Analysis

To assess the robustness of the results, the variability associated to the GHG emissions of ingredients, processing, and manufacture building blocks was individually assessed and propagated through the calculations. For most ingredients, only data at the impact assessment level (kg CO_2e per kg ingredient) were available, and therefore these were used to estimate and propagate variability. Consequently variability of individual datasets and uncertainty introduced by LCIA models were unavoidably mixed to some degree. This is not ideal, but many studies in the literature do not provide the LCI results, and it was felt that including the variability somehow was more important than ignoring this altogether or focus on the few studies that offer LCI information (which would have forced a much reduced number of less

[1] Representative product types were selected as those with the highest sales volumes. Part of the total Knorr production volume has not been specifically studied, but extrapolated from these main product groups.

representative building blocks). For most processing technologies and manufacture (and some ingredients), variability was assessed at the level of inventory inputs (energy use).

In this work, a lognormal distribution was fitted to the values found whenever two or more datasets were available. When only one dataset was available, the Data Quality Indicator (DQI, Weidema and Wesnæs, 1996) approach was used to evaluate a measure of variability from the uncertainty in the datasets, in a similar way as suggested in ecoinvent (Frischknecht *et al.*, 2008). The propagation of variability through the LCA calculations was assessed with 10,000 runs of Monte Carlo simulations in GaBi 4 Analyst Tool for each meta-product. Due to the fact that GaBi Analyst does not yet work with lognormal distributions, skewed normal distributions were modelled by adding different values to the lower (-SD) and upper (+SD) bounds of the Monte Carlo assessment.

3. Results

3.1. Meta-product level

Figure 1 shows the GHG emissions per tonne (squares and whiskers) and the contributions of each life cycle stage (pie charts) for dehydrated soups. Similar results were calculated for wet soups; bouillon cubes; liquid bouillons; and fruit shots, but are not shown here. The squares provide the median values of GHG emissions per tonne of finished product (as sold); the whiskers show the 10th and 90th percentiles from the Monte Carlo simulations.

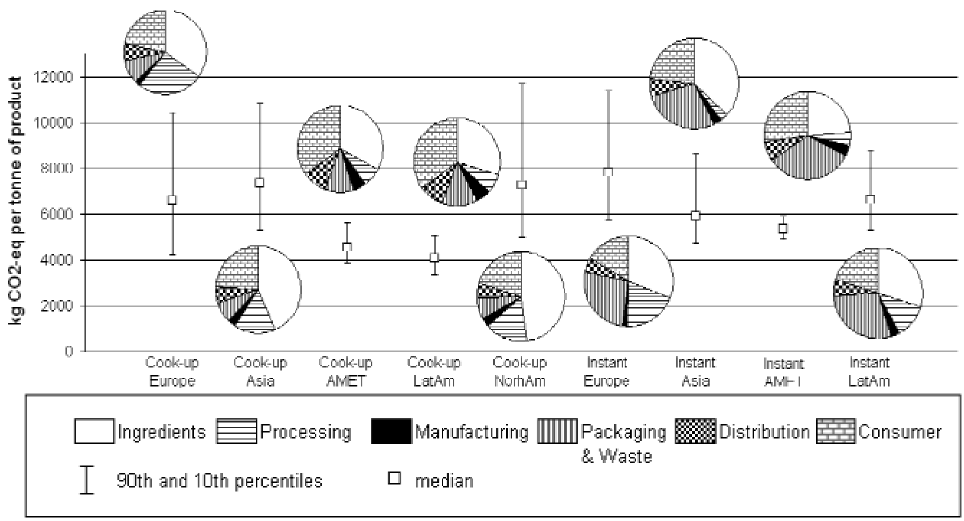

Figure 1: GHG emissions in kg CO_2-eq per tonne of finished product for the dehydrated soup meta-products assessed in the different regions

The relative contribution of each phase varies according to geography, consumer preference (flavour) and consumer use patterns. Some general findings were:

- Invariably, the best opportunities for GHG emissions improvement (i.e. the biggest hotspots) lie upstream or downstream from the Knorr factories (Manufacture stage,

black sector in Figure 1), which only represent an average of 4% of the emissions when considering the whole Knorr portfolio.
- In general, ingredients' production (white sector) and the use stage (horizontal bricks in Figure 1) have the highest contributions to GHG emissions.
- Ingredients' processing and packaging production also tend to have significant contributions to the total GHG emissions; these vary significantly across products.
- The packaging for instant dehydrated soups has a higher contribution that that for cook-up soups (Figure 1); this is due to the outer cardboard box present in instant soups (and not in cook-up ones).

When looking at the whole portfolio (not shown), product format is important:
- Dry and concentrated products tend to have a lower carbon footprint per portion than similar wet products, even though their carbon footprint per kg is higher because they do not contain water in the recipe (this is only added by the consumer).
- The energy required to dehydrate ingredients for one portion of dry products is generally lower than that required to sterilize / pasteurize one portion of a ready to use wet products, which has a larger mass.
- Dry products require less packaging than wet products and are more efficient to transport.

The lognormal distribution assumed for the values of most parameters propagates into the "error bars" shown in Figure 1, with fewer values between the median and the 10th percentile than between the median and the 90th percentile. The spread around the calculated medians varies substantially across meta-products, with some showing 80% of the values (10th-90th percentiles) within +-10% of the median and some meta-products spreading between -30% and +60%. Such variability in results is to be expected in bio-based products. However, and in addition, the grouping performed with ingredients and some of the processing technologies explains part of the large variability considered for some of the 'building blocks', which in turn explains why variability is much larger for some meta-products (i.e. those using a large share of ingredients with large variability). This second component of variability could be reduced if ingredient groups which contain too diverse elements were disaggregated.

3.2. Brand level

The aggregated Knorr brand CF is shown in Figure 2 and is estimated to be in the region of 3-5 million tonnes CO_2e/annum (95% confidence interval). At a brand level the hotspots are ingredients' production (e.g. fertiliser and energy use to grow crops and animal products; energy use to produce flavours and other ingredients; etc.) and home cooking of Knorr products each representing one third of the global CF. Primary processing of raw materials (e.g. energy use for activities such as drying, concentration of fruit and vegetables, and freezing) and the production of packaging materials each contribute about 10% to the total footprint; product manufacture in Knorr factories contributes about 4% to the total GHG emissions. Though ingredients for Knorr products are sourced from around the world, following the seasons to ensure quality and variety, transportation across the life cycle (including that of ingredients and final product distribution but excluding consumer purchase) accounts for 3% of the Knorr brand CF.

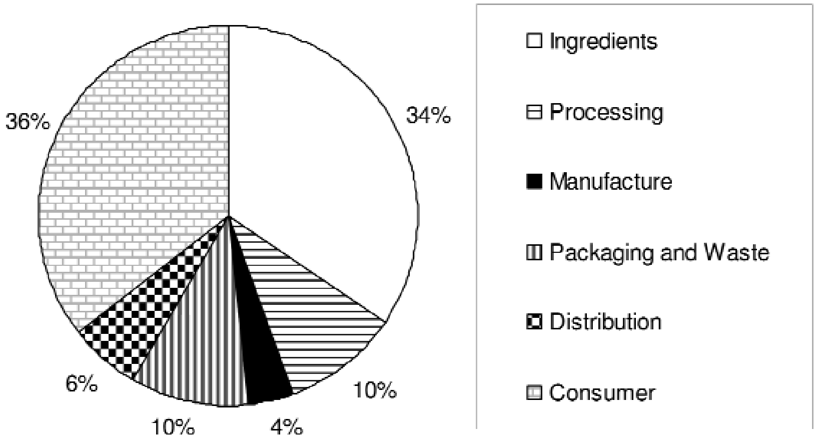

Figure 2: Relative contribution of the lifecycle stages for the total annualised sales of Knorr products globally

4. Discussion and Conclusions

The study presented here is the world's first life cycle GHG assessment at brand level including product portfolio analysis, and shows how a simplification of the study system made feasible the assessment of a complex problem. Lack of data availability has been overcome by resourcing to a variety of data sources and by grouping ingredients and processing technologies into a limited number of 'building blocks'. Considering variability reduces the discriminatory capacity between ingredients and eventually between meta-products (Lloyd and Ries, 2007), but also enhances the robustness of the results (Milà i Canals *et al.*, in preparation): we are more certain that the impacts lie within the range suggested, even though we cannot always say whether meta-product A is better than B. In any case, inter-product comparison was not a goal of this study, and it would be misleading anyway given that the different meta-products provide different functions (e.g. many have different portion sizes). Thus, the variability assessment greatly supported the interpretation by identifying a confidence range around the GHG footprint for both meta-product and brand assessment. It confirmed that the results presented here are useful for strategic decisions, where orders of magnitude and directional trends suffice. The size of the variability range around the data also indicates that the current data quality is inappropriate to support single number on-pack carbon labels of products particularly given the complexity of many supply chains. Further work is needed to disaggregate the ingredient groups related to the largest variability. However, even if several ingredients were not grouped for practicality, their inherent variability would probably still make the final result too imprecise for labelling. Communicating GHG footprint results as a range rather than single points would be more credible and useful for strategic decisions and B2B communications, but less understandable for the consumers.

The biggest opportunities for reducing GHG emissions lie upstream and downstream from the Knorr factories. Ingredients' growing and processing are one key area where engaging and influencing suppliers' practices may lead to significant GHG savings. Unilever has a long-standing history of working with farmers around the world to reduce their environmental impacts through the Sustainable Agriculture programme. Unilever's long-term aim is to buy its agricultural raw materials from sustainable sources; activities are being implemented to ensure the sustainability criteria include low carbon farming practices. Opportunities in the use phase include working on products requiring less heating at home. Unilever continues to invest in reducing the GHG emissions from its own operations; for Knorr, this is particularly crucial for wet products, where work is underway to reduce heat requirements of sterilisation and pasteurisation processes and increase the share of cleaner energy sources in Knorr factories.

The main advantage of the 'meta-product' approach presented here is that it simultaneously allows for the assessment and comparison of individual product types as well as for the estimation of a brand's total CF. The former is important in terms of finding ways to reduce GHG emissions associated with existing products as well as driving innovation for lower carbon products; Knorr is using the results of this study to inform product innovation yielding less environmental impact. It can also provide a baseline against which the brand could set targets and track performance and form the basis for communication.

The approach presented here is being used in all product innovations and used as one of the decision criteria to proceed or stop innovation projects. The level of accuracy provided is enough, given the quality of data available, to inform product developers on the potential trends of innovations in terms of GHG emissions, putting them in an excellent position to manage such emissions. Such automation of the GHG assessment process has been made possible through the model simplification (Rigarlsford *et al.*, 2010).

The study presented here focuses on one single environmental impact. A life cycle perspective is also important to address other sustainability issues either at an operational or strategic level, addressed with e.g. ingredient certification (sustainable sourcing). Even though consumer attention to CF is high, sustainable sourcing efforts are also high in the agenda. At a wider level, sustainability issues are only one of the aspects the consumer will look for, in addition to nutrition, taste, perceived quality, convenience, price, etc.

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Life-cycle water use, nutrient cycling and solid waste generation of a large-scale organic dairy

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ABSTRACT

Aurora Organic Dairy (AOD) is a leading U.S. provider of private-label organic milk and butter, managing over 12,000 milking cows and processing over 84 million liters of milk annually. Building on a previous life-cycle energy and greenhouse gas study, this paper benchmarks AOD's nutrient cycling, water use and solid waste generation across the life cycle of producing, processing and distributing fluid milk. Nutrient flows relevant to the impact categories of aquatic eutrophication and acidification were calculated. The acidification potential of AOD fluid milk across the full life cycle is estimated at 1.2 moles H+/ liter packaged milk. The eutrophication potential is 0.66 g N eq. / liter packaged milk. Water use refers to all water that is withdrawn from the natural hydrological cycle and used in various production processes and is divided into consumption and utilization according to Koehler (2008). This study includes all direct water use at AOD's facilities, as well as indirect water use associated with feed production, electricity generation, and the production of liquid transportation fuels. Total life cycle water consumption equals 808 liters water per liter of packaged milk, and life cycle water utilization is 12.3 liters water per liter of packaged milk. Municipal solid waste (MSW) generation at AOD facilities was estimated and characterized. National averages on recycling rates for AOD packaging types were utilized for end of life impacts. Across the whole life cycle, the production of one liter of packaged milk results in 42.3 g direct, 41.2 g indirect MSW, and 24.8 g recycled MSW. Packaging for the milk itself comprises a large portion (71%) of the direct MSW. Water use, eutrophication, acidification, and solid waste from farm operations are compared with total life cycle results to highlight the key inputs, processes, and stages influencing sustainability performance.

Keywords: milk, water use, nutrient cycling, nutrient use efficiency, solid waste

1. Introduction

Aurora Organic Dairy (AOD) is a large scale, vertically-integrated U.S. dairy, managing over 12,000 milking cows and processing over 84 million liters of private-label organic milk annually. To inform corporate sustainability reporting and improve upon environmental performance, AOD has engaged in a life cycle analysis of its fluid milk product. Life cycle energy use and greenhouse gas (GHG) emissions for AOD's fluid milk production have been previously reported (Heller & Keoleian, in review). This report investigates nutrient cycling (acidification and eutrophication potential), water utilization and consumption, and solid waste generation across farm operations, milk processing and distribution, consumer use and final waste disposal.

2. Methods

The AOD milk production system has been described in detail previously (Heller et al., 2008, Heller & Keoleian, in review; Gough et al., 2010). Data were analyzed over one year, from April 2008 to March 2009. The functional unit is defined as one liter of packaged fluid

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milk, composed of the fat-content and packaging-size product mix sold by AOD over the time period. The following sections provide a brief description of the methods used for the indicators considered in this report; for greater detail, please refer to Gough et al. (2010).

2.1 Nutrient Cycling

Agricultural productivity depends on the availability of nitrogen (N), phosphorus (P), and other elemental nutrients in farm systems. In order to meet the nutrient demands required for milk production, AOD imports large quantities of N and P nutrients embodied in feed, which then is converted into milk and manure in the farm systems. The nutrients contained within manures can then be released to the environment and lead to a variety of impacts. These impacts were quantified using eutrophication and acidification impact categories in LCA. The Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts (TRACI) 2 v3.0 (Bare et al., 2002; Norris, 2002) was used to quantify eutrophication and acidification impacts over the life cycle, and SimaPro software datasets were used for emissions outside of the farm operations stage. Within the farm operations stage, nitrous oxide (N2O), ammonia (NH3), nitrate (NO3-), and phosphate (PO4-3) releases were calculated. AOD records and expert opinion were used for direct data inputs and to configure models of the farm system. IPCC guidelines for reporting greenhouse gas emission were used for N2O releases and adapted to calculate NH3 emissions at the farm operations stage (IPCC, 2006). Nutrient contents in feeds, manure, milk, pasture leaching, and all other flows were calculated along with full farm-gate, soil-surface, and herd utilization balances for each farm system and nutrient (see Tables 9 and 10 and associated paragraphs in Gough et al. (2010) for methodological details).

2.2 Water Utilization and Consumption

Previous studies measure water use in terms of the water inputs to an industrial system, but because it is more important to understand the fate of water when it leaves the system, this study focused on water outputs from the milk production life cycle. Two types of water outputs are distinguished: water consumption – water that is evaporated, transferred to a different watershed, or incorporated into the final product; and water utilization – water that is used and then returned to the watershed from which it is withdrawn (Koehler, 2008).

This study quantifies water consumption and utilization in each stage of the milk life cycle. In the feed and bedding production stage, irrigation water that is evapotranspired by crops is counted as water consumption. The specific irrigation practices of feed growers were not known, so the U.N. Food and Agriculture Organization's CROPWAT 8.0 and CLIMWAT 2.0 (FAO, 2010) programs were used to determine the amount of irrigation water required to produce AOD's feed and bedding, taking growing locations into consideration. CROPWAT 8.0 provides theoretical estimates of crop water needs and tends to overestimate the amount of irrigation water used.

In the farm operations and milk processing and management stages, water consumption and utilization at AOD facilities were quantified based on AOD records, consultation with AOD experts, and literature sources. Additionally, the water consumption and utilization associated with electricity generation (Kenny et al., 2009; Torcellini et al., 2003) and transport fuel production (Wu et al., 2009; Younos et al., 2009) were estimated. In the later life-cycle stages (cold storage, distribution, retail and consumer/end-of-life), only water use associated with electricity and fuel was included.

2.3. Municipal solid waste

Municipal solid waste (MSW) is generated at every stage of the milk production life cycle and can cause significant environmental impacts. Recycling of MSW is one solution for reducing these impacts, but the U.S. Environmental Protection Agency states that "source reduction" of waste is the best strategy for reducing MSW impacts (EPA, 1999).

This study quantifies three different flows of MSW in the milk life cycle: direct MSW, indirect MSW, and the portion of MSW that is recycled. Direct MSW encompasses all solid waste generated as a direct result of AOD operations; major components include disposable udder wipes, filter socks, nitrile milking gloves, various types of packaging, and milk containers. Indirect MSW encompasses all solid waste generated during the production of electricity and processing of fuels (ash, sludge, etc). Recycled MSW encompasses a variety of waste flows diverted from the waste stream and returned for use as an input in an industrial process.

Data on direct MSW and recycled MSW were gathered from AOD purchase records, from AOD experts, and from literature sources referencing national average recycling rates (US EPA, 2008). This study excludes direct MSW generated during feed and bedding production due to lack of specific data. Indirect MSW was inventoried using Ecoinvent processes for electricity and fuel production (Ecoinvent, 2007).

3. Results and Discussion

3.1. Nutrient cycling

Figure 1 shows the distribution of acidification potential across the fluid milk life cycle. The acidification potential for the full life cycle is 1.2 moles H+/ liter packaged milk. Feed and bedding production and farm operations (which includes manure management) dominate the acidification impacts, with ammonia emissions contributing the most to overall acidification potential. It is important to note, however, that, due to a lack of appropriate data for organic production of major feed crops, datasets for conventional production of feed crops were used.

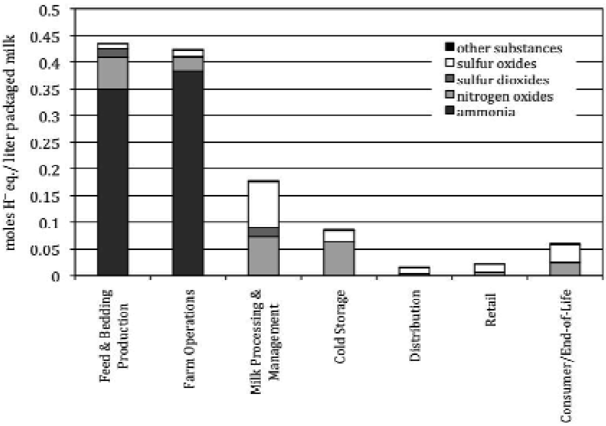

Figure 1: Acidification potential across the fluid milk life cycle. Figure also shows contributions from major emission substances.

Figure 2 shows the distribution of eutrophication potential across the fluid milk life cycle. Eutrophication contributions for the whole life cycle total to 0.66 g N eq. / liter packaged milk. Again, feed and bedding production is the major contributor to eutrophication, with nitrate leaching from fertilizer application being the dominant source. Eutrophication impacts remain uncertain, however, due to reliance on conventional crop production datasets.

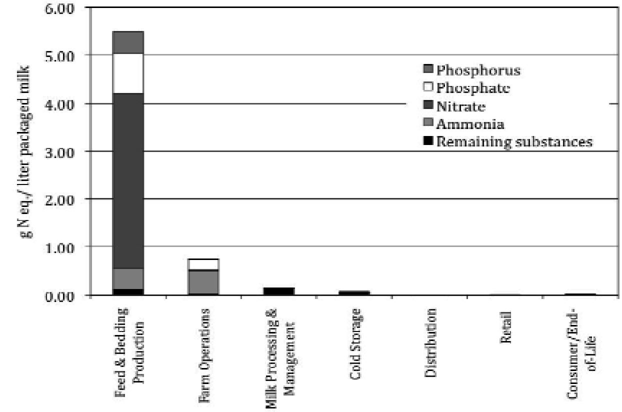

Figure 2: Eutrophication potential across the fluid milk life cycle. Figure shows contributions from major emission substances.

3.2. Water utilization and consumption

Life cycle water utilization and consumption is summarized in Figure 3. Irrigation of feed and bedding crops dominate water use (utilization plus consumption), accounting for 94% of the total life cycle water use. Pasture irrigation (included in "farm operations" in Figure 3) accounts for 3.2% of total life cycle water use. Total life cycle water consumption equals 808 liters water per liter of packaged milk, and life cycle water utilization is 12.3 liters water per liter of packaged milk. Irrigation practices on farms providing feed and bedding to AOD were not known; thus, irrigation requirement estimates were made using the evapotranspiration methods of FAO's CROPWAT software. This method often overestimates crop water needs for many crops (Pfister et al., 2009).

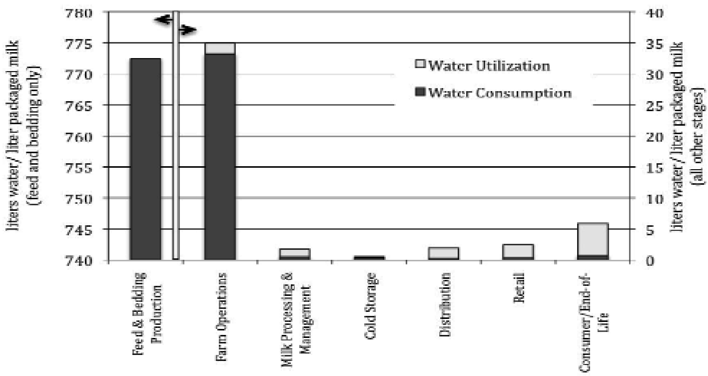

Figure 3. Water utilization and consumption across the fluid milk life cycle. Note that "feed & bedding production" scales to the left axis whereas all other stages scale to the right axis.

3.3. Municipal solid waste

The distribution of MSW across the major milk life cycle stages is shown in Figure 4. Across the whole life cycle, the production of one liter of packaged milk results in 42.3 g direct MSW, 41.2 g indirect MSW, and 24.8 g recycled MSW. Not surprisingly, the consumer/end of life stage accounts for the most MSW, contributing 71% of direct and 38% of indirect. Paper towels used for wiping udders during the milking process were the largest contributor to MSW in the farm operations stage, composing 73% of the direct MSW at this stage.

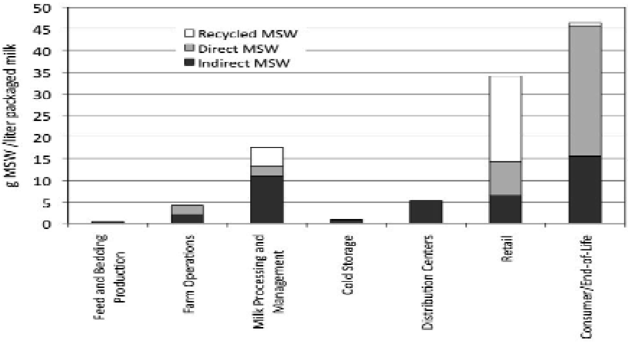

Figure 4: Municipal solid waste (MSW) generation across the fluid milk life cycle.

3.4. Impact distribution

Figure 5 summarizes the distribution of life cycle environmental impacts, including energy use and GHG emissions, across the major stages of the AOD fluid milk life cycle. Note that the impacts in this figure are weighted equally across impact categories, so the magnitude of peaks should be interpreted carefully. This begins to offer an interesting look at the "landscape" of environmental impacts for organic milk production via AOD's system. While some impact categories, such as water use and eutrophication, are highly concentrated in one life cycle stage (feed and bedding production), others, such as energy use, are relatively distributed across the life cycle.

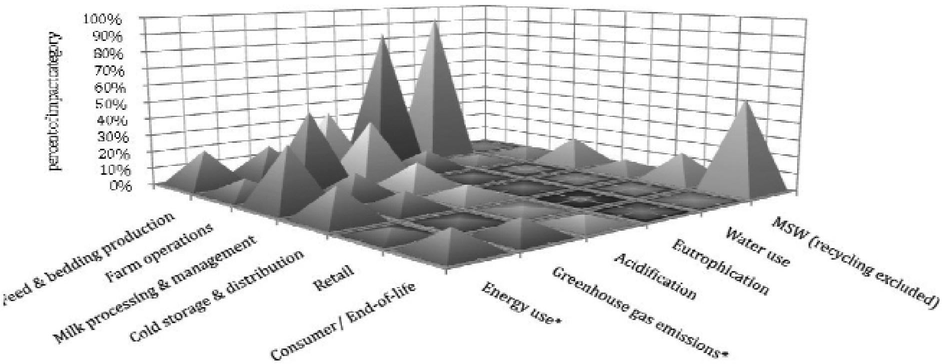

Figure 5: The environmental impact "landscape" across the AOD fluid milk life cycle. Percentages add to 100 for each impact category. *Energy/GHG reported in Heller & Keoleian (in rev.)

4. Conclusions

Life cycle assessment of food and agricultural systems is an emerging field challenged with difficult methodological decisions and sparse data resources. These challenges must be kept in mind when interpreting LCA results. Still, a concentrated case study, such as the AOD organic fluid milk system presented here, begins to offer a look at the complex interaction between an agricultural business and environmental performance. The pervious study (Heller et al., 2008; Heller and Keoleian, in review) introduced new approaches to co-product allocation, while this study adds impact categories especially relevant to agricultural systems. The present study is limited by poor data resolution in the "feed & bedding production" life cycle stage, important to nutrient, water, energy and GHG indicators. For studies such as this to move forward in properly informing decision-making, there is a strong need for LCA data on U.S. crop production for varying production practices (e.g., organic vs. conventional) and climatic regions.

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Life Cycle Assessment and Carbon Footprint in the wine supply-chain

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ABSTRACT

This study concerns the application of a Carbon Footprint (CF) tool to an Italian wine case-study to which Life Cycle Assessment (LCA) had already been applied, with the aim of testing this new approach and draw some preliminary comparative remarks. The functional unit used was a 0.75 litre bottle and the supply-chain considered started from the vineyard and ended with the sale of the product, including the transport related to the distribution stage. The results show that the considered tools are similar in terms of applicability, but differ in the outputs they produce. The CF is easier to understand than LCA, which provides more complete data. The studied sample does not permit us to make a meaningful assessment of the considered tools. In conclusion, further studies must be carried out to validate the use of CF in companies of different sizes, which may have significant environmental impacts also in other categories.

Keywords: wine industry, carbon footprint (CF), Life Cycle Assessment (LCA)

1. Introduction

The wine industry is a "global" sector, in terms of end market, which represents a significant demand of world resources. According to recent data almost 8 million hectares are used for viticulture and the estimated annual world production of wine is about 270 million hectolitres (OIV, 2006). With the increase in the size of this industry, related environmental problems are of growing concern. For a meaningful breakthrough towards environmental sustainability, integrated strategies are needed, both at a national and global level. In this context, low-impact products and technologies, as well as methods and tools that can assess the impacts related to the wine supply-chain, have recently gained increasing success. As is well-known, one of the most established methods is Life Cycle Assessment (LCA) (Point, 2008). To adapt to worldwide trends focusing on the Global Warming issues, the OIV (the International Organisation of Vine and Wine), while accepting the methodological structure of LCA, has decided to adopt a Carbon Footprint approach. Following the issue of the Guidelines for Sustainable Viticulture (OIV, 2004), OIV is working on the OIV-GHGAP (OIV-GreenHouse Gas Accounting Protocol) for the wine industry to standardise a methodology to establish the contribution of CO_2 emissions in the wine supply-chain. As a starting point, the OIV has taken the IWCCP (International Wine Carbon Protocol) and the relevant IWCC (Carbon Calculator) (FIVS, 2008), developed by an international consortium of winemakers' federations (Forsyth et al., 2008) and formally endorsed by the International Federation of Wine and Spirits (FIVS) (www.fivs.org). The Protocol and Calculator were designed primarily as a company-level tool in accordance with current international standards and practices for GHG accounting (ISO, 2006; BSI, 2008; Waye, 2008). The Protocol separates the emissions in three scopes: Scope 1, including all those emissions over which a company has direct control (cultivation, wine-making,

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bottling); Scope 2, referring to purchased energy; and Scope 3, including the emissions from all products/activities purchased from other companies. The Protocol expressly state that all emissions that represent more that 1% of the mass of the product, or more than 1% of total GHG emissions, should be included. Currently the calculation does not include all elements of the short-term carbon cycle (e.g., CO_2 from wine fermentation, emissions from combustion or breakdown of vine prunings, etc), as well as land use change, infrastructure items and assets (barrels, tanks and machinery), business travel of employees, and most chemicals.

The purpose of this work is the application of the above tool to a winery in Abruzzo, Italy, where an LCA had been already carried out previously (Petti et al., 2005, 2006). This study examines, in a context already known, the characteristics of an instrument (CF) which is still being defined. At the same time we try to make some preliminary comparative considerations concerning the two approaches considered (LCA and CF).

2. Case-study implementation

A preliminary implementation of the IWCC, version 1.3 (FIVS, 2008), to an Italian wine product was made by using inventory data from a previous LCA study (Raggi et al., 2005; Petti et al., 2006). The main goal of the above LCA case-study was to identify the most impacting life-cycle stages. The functional unit chosen was a bottle (750 ml) of organic red wine (Montepulciano d'Abruzzo), including primary packaging (glass bottle, shrink cap, cork and label) and secondary packaging (corrugated cardboard box, PVC film and wooden pallet). The farm analysed has 12 hectares of vineyard, 5 of which cultivated with Montepulciano d'Abruzzo grape. The average yearly production of Montepulciano grapes is about 70 tonnes. The yearly production of wine is about 50,000 litres, part of which (75%) is bottled, whilst the remaining is sold in bulk. The vineyard is cultivated according to organic farming standards. The winery's activities include winegrowing and making, bottling and sale of the finished product to local, national and international markets. All the above steps were included within the product system boundaries, while wine consumption, transport of auxiliary materials, and the product's end-of life phases were temporarily excluded (Petti et al., 2006). The collection of all production process inputs and outputs resulted in a database grouping all the operations carried out and the amounts of substances (fuel, chemicals, etc.) used in the various processes, as well as the output released throughout the reference year, according to the month of reference (Petti et al., 2005). The same database was used as a source for the data entered in the IWCC. The carbon calculator's parameters and emission factors remained unchanged, with the exceptions listed below. Prior and during the data entry phase a few assumptions and choices were made, as described in the following. Because the available data on the phases upstream bottling refer to the overall quantity of Montepulciano wine produced, these data were allocated on a mass basis between bulk and bottled wine (like in the LCA model), and the value shares allocated to bottled wine were used for data entry.

Scope 1: As regards mobile equipment, data on fuel consumption (diesel) for operating tractors and other equipment and for transporting workers to fields were entered; the carbon calculator allows the user to select the fuel type, but not the kind of equipment (tractor, lorries, etc); thus, fuel-specific CO_2 default emission factors were used in calculations, irrespective of the piece of equipment actually used. As regards the waste disposed of on-site, the amount of shredded grape stalks spread on fields and buried as a soil improver were entered in the "landfilled grape marc, pommace, grape stalks and stems" item.

Scope 2: The default CO_2 emission factor for the production of electricity was adapted to the Italian power mix: 668 g CO_2/kWh (European Commission, 2010). Since this emission factor is also inclusive of the transmission and distribution losses of electricity to the point of use, no specific correction factor for power transmission and distribution losses was entered in the relevant field of the IWCC. As a result of that, the whole GHG emissions related to power use were included in Scope 2 (in principle, the share related to distribution losses should be included in Scope 3) .

Scope 3: As regards packaging, since no specific data field was found in the IWCC for the bottle paper labels, the relevant data were entered as "paper" in the "Wine bags" category. For transports, the overall amount of kilometres travelled by the different types of vehicles used for product distribution were calculated, based on following information available for each of the main market area to which wine is delivered (regional, national and international): number of bottles delivered, average distance travelled from the firm to the final market, type of vehicle used and its loading capacity. Among the wine related products used, the only one for which a corresponding entry was found in the IWCC was bentonite. Therefore, it was not possible to enter the data on the other products, such as potassium metabisulphite, yeast, albumin. Similarly, it was not possible to enter any data on the chemicals and other inputs used in the bottling process (sodium hydroxide, nitrogen), as well as in agricultural practices (copper hydroxide, micronized sulphur, *Bacillus thuringiensis* bacteria, milk, glucose), because no relevant entries were found in the IWCC. The data concerning the input flows that we could not enter in the carbon calculator show a modest quantitative contribution in this case-study; however in a larger winery they might represent a higher value of associated environmental burdens. It should be stresses that also in the LCA implementation most of the above input flows were temporarily excluded from the analysis because relevant data were not found in the available databases (Petti et al., 2006).

Finally, the IWCC prompts the analyst to enter data on waste destined to leave the company. In our case, marc and lees – which are the only by-products leaving the company – instead of being disposed of, are delivered to a distillery for further processing into alcohol and other derivatives. Therefore, it was decided not to enter any data within these items. Indeed, a more accurate modelling would require an allocation process (or alternative approaches) to deal with the environmental burden shared by the main product and by-products; however, no allocation (or alternative option) seems to be possible in the IWCC.

After the data entry and all the relevant checks were completed, the GHG emissions summarizing the results of the study – which are automatically tabulated and plotted by the IWCC – were considered and analysed.

3. Results and discussion

Figure 1 shows the scope comparison, where out of the total emissions generated, those deriving from products and activities that come from outside the company (Scope 3) are responsible for 88% of the total impacts while a 11% share is represented by the company's direct emissions (Scope 1). Power consumption (Scope 2) is negligible compared to the other components. The chart in Figure 2 shows that 70% of the GHG emissions included in Scope 1 are caused by the on-site disposal of solid waste (grape stalks) generated in the wine-making stage. A 29% share comes from the operation of mobile equipment and on-site transportation. The remaining 1% is attributed to the emissions from organic fertilisers (manure) spread on cultivated land. Figure 3 clearly highlights that the contribution of packaging represents a large part of the emissions deriving from processes external to the company (Scope 3): globally 93%, mainly from glass bottles. About 7% of emissions are attributed to the distribution of the final product.

If GHG emissions are compared irrespective of the scope (Table 1), it can be clearly seen that the production of bottles is by far the most impacting issue (47 tonnes of CO_2-eq, i.e. about 70% of the total GHGs released). The other packaging materials are responsible for the emission of further 10 tonnes of CO_2-eq. (about 15% of the total), thus definitely making wine packaging the most critical GHG contributor in this case-study. Other activities, such as product distribution, mobile equipment operation, power use, contribute marginally. About 5 tonnes of CO_2-eq. are attributed to shredded grape stalks disposed of on-site. In this case, the Protocol provides that, for the disposal of waste (stems in our case) in the soil, a correlated emission of methane is considered (FIVS, 2008 p. 57; IPCC, 2006). However, it should be stressed that, given the soil improving effect of spreading organic waste, the use of alternative substances (soil improvers, fertilizers) is reduced, resulting in avoided GHG emissions related to their production. Unfortunately, that counterbalancing effect is not considered by the IWCC.

We are well aware that a direct comparison of the results obtained by implementing LCA (limited to the Global Warming Potential results) (Petti et al., 2006) and CF to this case-study, despite being mainly based on the same original data collected on-site, may have a limited scientific meaningfulness, also because modeling was not exactly the same in both cases. Nevertheless, we would like to notice that there were similarities, between the two instruments used, in the relative results obtained. Indeed, if the LCA results for GWP (Petti et al., 2006) are examined, it emerges that the major contribution in terms of emissions (more than 70%) comes by far from packaging (in particular: the glass bottle), followed by the product distribution and the agricultural operations. Therefore we could state that the results of this CF implementation were in rather good agreement with those of LCA.

Nevertheless, some shortcomings emerged during the implementation. As also recognized by the authors themselves (FIVS, 2008), the list of products and inputs available is limited to just a few wine related products, while chemicals and other inputs used in the other life-cycle stages (viticulture, bottling) are completely missing. Moreover, most default model parameters and assumptions are closely linked to the Countries/Regions where the organisations that initiated the tool development are located.

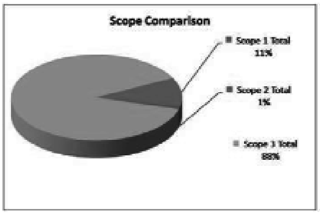

Figure 1: Scope Comparison

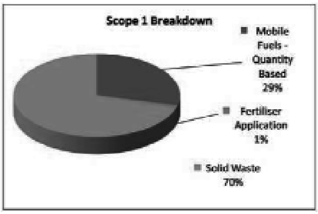

Figure 2: Scope 1 breakdown

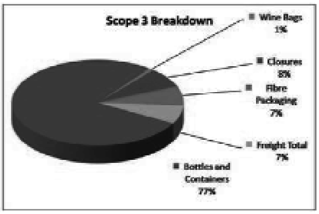

Figure 3: Scope 3 breakdown

Table1: General summation – Comparison of all emissions

Category	Quantity (tonnes CO_2-eq)
Bottles and container	47.3
Closures	4.6
Solid waste	5.4
Fibre Packaging	4.5
Freight total	4.3
Mobile Fuel	2.0
Fertiliser application	0.8
Labels	0.5

When co-products are obtained in the same process, specific modeling options may be required. For instance, if one refers to the case-study discussed here, burden allocation was needed among winemaking by-products (marc, lees) and the main product (wine), or between bottled and bulk wine. Although still debated, allocation and system expansion options are well developed in LCA software. Instead, these options do not seem to have been considered in the IWCCP, probably as a result of the predominantly company-orientedapproach followed by that tool. Similarly, if wastes are recovered, the avoided environmental impacts due to the prevented production and use of alternative substances or products can be credited to the system. For instance, in this case study, grape stalks are recovered by spreading them on agricultural land as a soil improver. This can be conventionally modeled by system expansion; however, in the IWCCP the related avoided impact could not be credited to the wine product system.

In the IWCCP Scope 1 and 2 are considered as the only ones directly controlled by a firm's management. Actually, firms' strategic choices can often affect the environmental impacts of their products in the upstream and downstream supply-chain stages (e.g.: by selecting more environmentally-sound raw materials, facilities or logistics solutions, or by designing their products to make them more easily recycled). In fact, a fully integrated product-oriented (rather than company-oriented) approach would be more effective in making companies fully aware of their role in determining the environmental performance of their products and avoiding environmental burdens to be shifted from one life-cycle stage to another. Moreover, despite the significance of global warming, its sole consideration in evaluating strategic options of a company – and, therefore, in guiding the purchasing decisions of consumers – may result in shifting environmental impacts from global warming to another issue, instead of improving the overall environmental performance. For instance, in the agricultural stage (e.g.: viticulture), if we consider organic versus conventional farming, the former usually requires a larger amount of mechanical operations than the latter (e.g., for mechanical weeding as opposed to chemical one), thus potentially causing a greater impact on global warming, due to fuel combustion. However, this might be offset by a lower impact on ecosystem- and human toxicity, as a result of reduced spreading of herbicides. Therefore, focusing merely on global warming would not highlight this impact shift: this can be a serious limitation of the CF approach.

On the other hand, the CF approach, because of its higher immediacy and ease of understanding, implied by the use of a single indicator, is more suitable than LCA to be used as a clear , albeit incomplete, means of communication of environmental performance

4. Conclusions

The wine industry has been increasingly impelled by market and regulatory drivers to assess and reduce carbon emissions. The need to develop a consistent and objective methodology has been perceived by some organizations and the OIV, which are developing an *ad hoc* instrument. In this study, this tool has been implemented to a wine product which previously undergone LCA. As expected, despite a few differences in framework and modelling, results concerning global warming are rather consistent. Nonetheless, as regards the CF tool, the lack of accurate baseline data was confirmed and the need of further improvement and adaptation to additional contexts was highlighted. In conclusion, it can be stated that the calculator carries out an accurate assessment of emissions as it contains effective tools capable of providing concise information analysing all phases of wine production. However, LCA seems to be more effective in avoiding environmental burdens and impacts to be shifted from one life-cycle step to another, or from one environmental concern to another. On the other hand CF seems to be more suitable as a marketing tool.

We feel, therefore, that the study started with this paper should be continued with the aim of broadening the research boundaries (more companies and products) and diversifying the characteristics of the sample (larger companies). In this way a more accurate definition of the variables of interest (production stage or inputs), which contribute the largest amount of emissions from the chain, can be defined with greater accuracy.

Acknowldgements: *We would like to acknowledge the kind cooperation of the other co-authors of the LCA study here cited, Dr. Camillo De Camillis and Prof. Luigia Petti, in providing the original data and commenting on them.*

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Water use in the life cycle of food products from Brazil

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ABSTRACT

All over the world the highest water use is for agricultural activities (70%), followed by industry (20%) and domestic use (10%). So it is very important to understand where and why the water is being used in agriculture, besides considering the possibilities of water use reduction along the life cycle of agricultural products. This contribution considers the aspects of water use in two important Brazilian crops: coffee and orange. The water used by these crops in the main Brazilian producer regions of Minas Gerais and São Paulo States was assessed by LCA. The average water use estimated for these crops was approx. 11,400 kg of water / 1,000 kg of green coffee and 2,500 kg of water / 1,000 kg of orange. Both crops showed large differences among the farms evaluated. The differences observed among the farms are discussed in terms of agricultural practices adopted. LCIA was applied for interpreting these results.

Keywords: Water use, Food, Life cycle, Brazil; Sustainability

1. Introduction

Water is fundamental for life and its conservation through reduction of waste water generation, R&D to minimize the water use and waste water generation, treatment and reuse of water and source preservation are needs we must manage. Approx. 30% of the world water distribution is attributed to South America, followed by South and East Asia (26%), North America (15%) and East Europe (10%).

On the other hand, the world water consumption is similar for several regions (14-16%) with the exception of North America and Europe which have relatively lower water use (6-7%). All over the world the highest water use is for agricultural activities (70%), followed by industry (20%) and domestic use (10%) (FAO, 2003).

Due to the relevant contribution of agriculture activities to water use there are studies with the aim of investigating the water use of different crops, e.g. broccoli (Milà i Canals et al. , 2008), onion, tomato, potato, pepper and cabbage (Pfister et al., 2008). In the study case on LCA of FCOJ, the orange cropping step was the greatest contributor to the water use in the life cycle of the product (Coltro et al, submitted). So it is very important to understand where and why the water is being used in agriculture, besides considering the possibilities of water use reduction along the life cycle of agricultural products.

There are also proposals of methodologies to assess the environmental impacts related to the water use (Owens, 2002; Chapagain, Orr, 2009; Milà i Canals et al., 2009). Chapagain and Orr (2202) named virtual water the amount of water that is required to produce a certain product which can also be expressed as a water footprint. According to this methodology, the water used for crop production is composed of two components: 1) the evaporative water that is the sum of the evaporation of rainfall from crop land (green water use) and the evaporation of irrigation water from crop land (blue water use), and 2) the non-evaporative water

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that is the polluted water resources resulting from leached fertilizers, chemicals or pesticides from agricultural land.

So, this contribution considers the aspects of water use in two important Brazilian crops: coffee and orange. LCA assessed the water use of these crops in the main Brazilian producer regions as follow: four Brazilian coffee producer regions located in Cerrado Mineiro, South of Minas Gerais State, Marília and Alta Mogiana regions in São Paulo State and two Brazilian orange producer regions located in the North and South of São Paulo State (Coltro et al., 2006; Coltro et al., 2009).

2. Methods

2.1. Studied systems and system boundaries

Water use related to the production of green coffee and orange for FCOJ in Brazil has been studied on a cradle to gate approach, i.e. up to the distribution of the product to a Brazilian export harbor (green coffee) and processing plants (orange) (Coltro et al., 2006; Coltro et al., 2009). In those studies more details on the system boundaries can be found.

The reference crops 2001/02 and 2002/03 of the green coffee produced in Brazil were studied. A total of 56 properties located in four Brazilian coffee producer regions were evaluated: Cerrado Mineiro and South of Minas Gerais regions in Minas Gerais State, and Marília and Alta Mogiana regions in São Paulo State. The data refer to a production of 420,000 bags of coffee beans and a productive area of approx. 14,300 ha.

The reference crop 2002/2003 of oranges produced in the State of São Paulo, in Brazil, was studied. The State was divided into two orange-growing regions - North and South. The data refer to a production of 367,200 metric tons (9 million boxes) of oranges, 4 million plants in commercial production and an evaluated area that accounts for 19.5% of total orange production in the State of São Paulo.

Farm specific data along with agricultural production data have been combined to elaborate the coffee and orange cultivation inventories which were employed to estimate the impact of water use of these crops. For both products the adopted functional unit was the production of 1,000 kg of product.

2.2. Impact pathways

According to Milà i Canals et al. (2009), there are four main impact pathways related to freshwater use that may be distinguished and merit attention in LCA: 1) Direct water use leads to changes in freshwater availability for humans leading to changes in human health; 2) Direct water use leading to changes in freshwater availability for ecosystems leading to effects on ecosystem quality (freshwater ecosystem impact – FEI); 3) Direct groundwater use causes reduced long-term (fund and stock) freshwater availability (freshwater depletion – FD); 4) Land use changes leading to changes in the water cycle (infiltration and runoff) leading to changes in freshwater availability for ecosystems leading to effects on ecosystem quality (FEI). Only the impacts on ecosystem quality (from direct water use) were considered in this contribution.

2.3. Water flows quantified in LCI

Following the inventory modeling for assessing freshwater use impacts in LCA described by Milà i Canals et al. (2009), from a freshwater ecosystem impact point of view, the following water flows were accounted for in LCI: surface and groundwater evaporative uses, i.e. in-stream evaporation in reservoirs and power dams and off-stream evaporation of abstracted water through irrigation. In terms of virtual water, the evaporative blue water was accounted for since this water can be linked to impacts on ecosystems.

2.4. Characterization factor for LCIA

Water Use Per Resource (WUPR) indicator was used as a characterization factor for FEI. Since the WUPR for Brazil is 0.7% (Milà i Canals et al., 2009), the characterization factor adopted was 0.007.

3. Results and Discussion

3.1. Green coffee

The average water use estimated for the coffee crop was approx. 11,400 kg of water / 1,000 kg of green coffee. This crop showed large differences among the farms evaluated as can be seen in the Figure 1. The farms 18 and 23 located at Mogiana region (SP) showed the highest water use values, very far from the weighted average. Both farms employed the dry method to 100% of their coffee production. So, the highest water use is due to the water employed for washing and separation of the coffee berries for preparing the yard coffees, since there is no irrigation in the coffee crop.

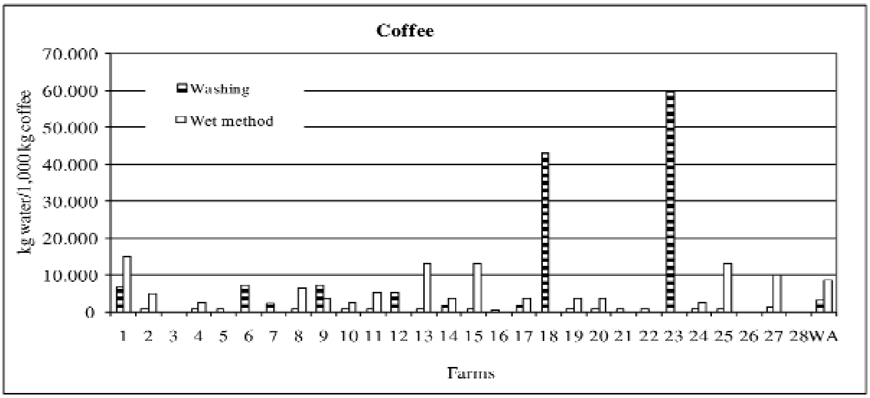

Figure 1: Water use for coffee crop and processing at several farms located at: 1 to 12 - South of Minas Gerais region (MG); 13 to 16 - Cerrado Mineiro region (MG); 17 to 25 - Mogiana region (SP) and 26 to 28 - Alta Paulista region (SP). WA = weighted average.

Nevertheless, when the weighted average of the coffee produced by the farms evaluated in this study is considered it can be observed that the water use by the wet method is approx. triple of the dry method which uses water only for washing (Figure 2). By far the farms located in Minas Gerais State uses much more water than the farms located in São Paulo State.

Applying the contribution analysis to the water use of the farms 1, 13, 14, 19, 25 and 27 (56% of the coffee produced by the farms evaluated) it is possible to note that the higher water use is due to the cropping, with a little contribution of the electricity grid and even lower contribution of the transport step (Figure 3). Despite 60% of the coffee produced by the farm 13 was based on the wet method for obtaining the washed coffees or coffees without pulp, this farm showed lower water use than farms 1 and 25 which used 30-33% of wet method. In this case the water use was more dependent on the farm management than the processing method.

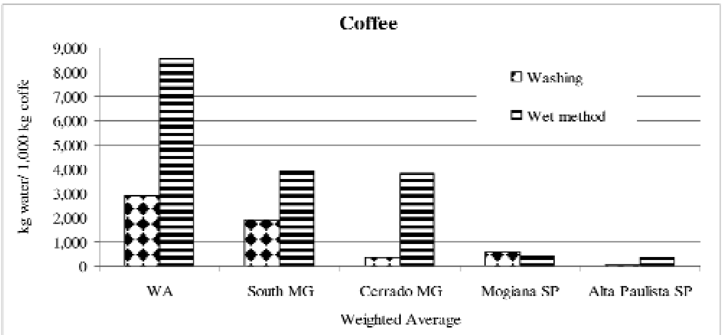

Figure 2: Water use for coffee crop and processing (pulp and mucilage removal): WA – weighted average of the all farms evaluated; South MG, Cerrado MG, Mogiana SP and Alta Paulista SP - weighted average per each region.

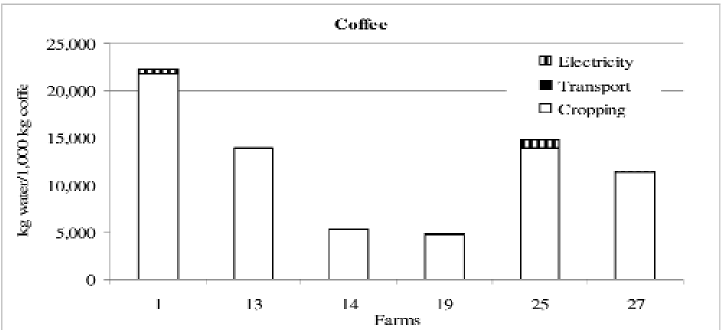

Figure 3: Contribution analysis of the water use for coffee crop and processing at farms located at: 1 - South of Minas Gerais region (MG); 13 and 14 - Cerrado Mineiro region (MG); 19 and 25 - Mogiana region (SP) and 27 - Alta Paulista region (SP).

Since the water used in the coffee crop is non-evaporative which is subsequently returned to the water source it does not lead to relevant environmental impacts from a resource perspective. However environmental impacts related to other impact categories can be associated to this water use, e.g. eutrophication due to fertilizers use but this is not the focus of this study.

3.2. Orange

The average water use estimated for the orange crop was approx. 2,500 kg of water / 1,000 of orange. This crop also showed large differences among the farms evaluated as can be seen in Figure 4. Mainly surface water is used for orange cropping, with the farms 11 and 22 showing the highest water use. The high water use of these farms is due to the water employed for irrigation of the orchards.

The weighted average of water use by the North and South regions of São Paulo State is quite similar (Figure 5). The amount of water used in the North region is higher for incomes and disinfection than for irrigation, while the water used in the Southern region is basically for irrigation. In both regions mainly surface water is used.

The contribution analysis of water use by the orange crop showed a little contribution (approx. 10%) of the electricity grid for the Northern region (results not shown).

Considering the impact assessment, Figure 6 shows the results of the impact category Freshwater Ecosystem Impact (FEI).

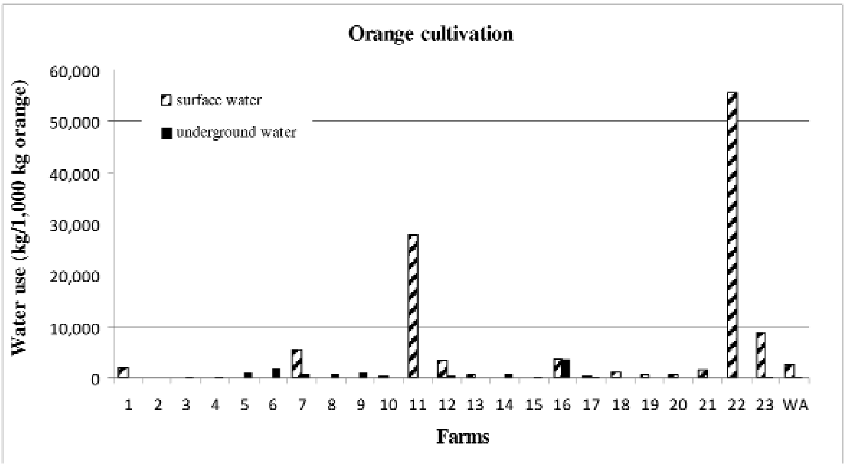

Figure 4: Water use for orange crop at several farms located at: 1 to 13 – Northern São Paulo State region and 14 to 23 – Southern São Paulo State region. WA = weighted average.

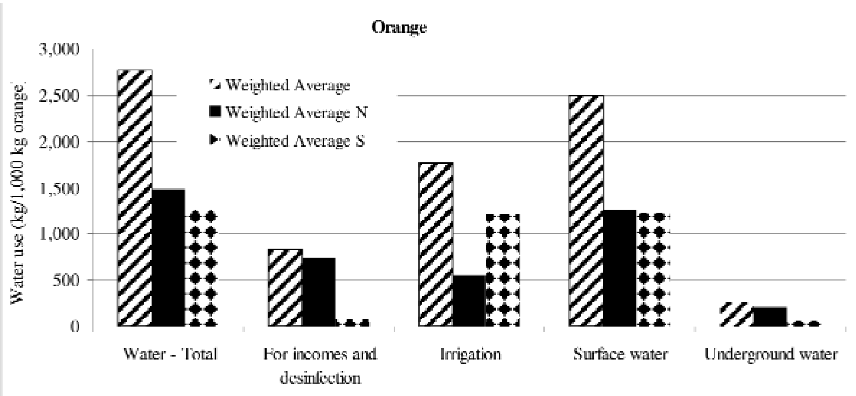

Figure 5: Weighted average (total end per region) of water use for orange crop.

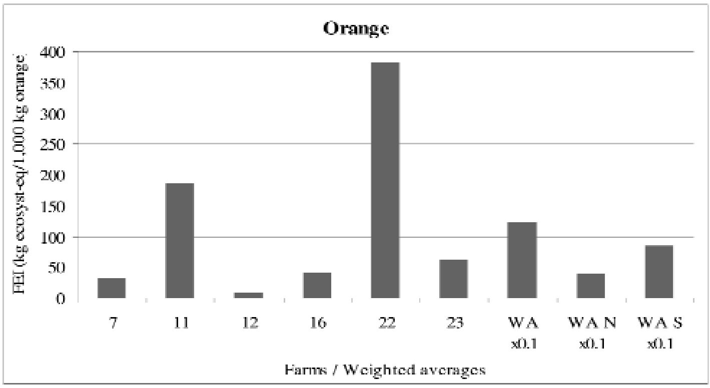

Figure 6: Freshwater Ecosystem Impact (FEI) for orange crop due to direct evaporative blue water use: 7 to 23 = farms that employ irrigation of the orchards; WA = weighted average whole sample; WA N and WA S = weighted average per region.

Applying the characterization factor to the results did not change the profile of the farms since the results were multiplied by the same factor 0.007, which means that only 0.7% of water resources are being used in Brazil. Even considering a more localized factor, e.g. river basin, the profile of the results obtained should be the same since the orchards are all located in the State of São Paulo and in the same river basin, Parana that has a water stress indicator, WSI = 3.4% .

However, the FEI translates the total water used in the LCI of this crop to a value that expresses the environmental impact of this activity on the resources. The high difference between the FEI of the farms 22 and 23 probably is related to the efficiency of the irrigation adopted by them since both are located in the same municipal district.

The FEI could be improved if the water quality available (level of pollution) was also considered and not just the water volume. In this way, water use could be differentiated depending on the regions of the same river basin.

4. Conclusions

The results showed that although the water use of the coffee crop is higher than the orange crop, the water used for coffee cropping has no environmental impact on the resources since the water is non-evaporative. On the other hand the orange crop has some freshwater environmental impact due to the water used for irrigation of the orchards.

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Dryland and irrigated cropping systems: comparing the impacts of consumptive water use

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ABSTRACT

This study highlights the importance of including impact assessment in the development of life cycle-based sustainability indicators relating to consumptive water use. For cereals grown in the large Australian state of New South Wales, a 150-fold difference in water footprint was found between the major Statistical Divisions when calculated using the method of Ridoutt and Pfister (2010a), reflecting variation in the use of supplemental irrigation and local water scarcity. These differences were not evident when virtual water contents were compared. For cereals grown without irrigation, inputs to farming (fertilizer, etc) made the major contribution to the water footprint.

Keywords: wheat, barley, oats, water footprint, impact assessment

1. Introduction

Freshwater has become a scarce and overexploited natural resource in many parts of the world with serious consequences for global food security and the health of freshwater ecosystems (Rockstöm *et al.*, 2009; Ridoutt and Pfister, 2010b). This has led to recent developments to incorporate consumptive water use into life cycle assessment (LCA) (Berger and Finkbeiner, 2010) as well as parallel developments in water footprinting where an ISO standard, coherent with the ISO 14040 series, is now in development (TC 207/SC5/WG8). Developments in water footprinting are occurring in response to widespread demand for streamlined LCA-based sustainability indicators which can support sustainable patterns of production, consumption and investment. The leading example is carbon footprinting.

Early attempts at product water footprinting (e.g. Chapagain and Hoekstra, 2007), building on the concept of virtual water, described volumes only and lacked an adequate consideration of the system boundary as practiced in LCA. Although these early studies have been widely reported in the popular media and have been influential in heightening public awareness of the indirect nature of freshwater consumption (i.e. through the consumption of goods and services), product water footprints calculated using these methods are problematic (Ridoutt *et al.*, 2009b). Volumetric water footprints, when reported as a single value (e.g. 40 l per slice of bread, 5,000 l kg^{-1} cheese, www.waterfootprint.org), provide no indication of the potential harm associated with consumptive water use. Regionalization is a critical issue in assessing the impacts of consumptive water use, as is the source of freshwater being used. For example, the potential harm associated with consumption of so-called green water, derived from natural rainfall over agricultural lands, is not equivalent to so-called blue water, abstracted from surface and groundwater resources. This is an acutely important issue in comparing alternative dryland and irrigated production systems.

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Our research concerns the application of an LCA-based water footprinting method (Ridoutt and Pfister, 2010a) to assess the impacts of consumptive freshwater use in wheat, barley and oats production in the large Australian state of New South Wales (NSW). In the year of analysis, more than 5 M ha of these crops were grown, producing more than 11 M t of grain using a range of dryland and irrigated cropping systems. Our purposes were threefold: Firstly, to provide baseline data on these common agricultural commodities useful to downstream food manufacturers; secondly, to explore the variability between production systems and regions in terms of potential to contribute to freshwater scarcity; and finally, to compare the relative importance of irrigation, the water used in the production of farm inputs, and emissions of fertilizers to freshwater in contributing to the overall product water footprint.

2. Methods

2.1. Crop production and irrigation water use

This study is based on the most recent farm production and water use statistics published by the Australian Bureau of Statistics (ABS) at the level of the Statistical Local Area, i.e. the 7125 and 4618 data series covering the year 2005/06, released in 2008 (www.abs.gov.au). For NSW, the focus was the six major grain producing regions, which in 2005/06 accounted for more than 99% of the State's wheat, oats and barley production (Table 1). Whereas the ABS 7125 data series describes the production of specific grains, the ABS 4618 data series reports water use for the broad category of *cereal crops for grain or seed (excluding rice)*. Therefore, the ABS data does not describe the area of wheat, barley and oats grown under irrigation, nor does it describe the volume of irrigation water specifically applied to these crops. In NSW, the cereal crop (excluding rice) that is most commonly irrigated is maize. Therefore, for each Statistical Local Area where maize was grown, irrigation water use was estimated using the APSIM modelling platform (Keating *et al.*, 2003) to reproduce yields consistent with the ABS data. The balance of the water use reported by ABS was then distributed to the other cereal crops based on expert opinion regarding the relative likelihood of irrigation and application rates (Table 2). This approach gave priority to the ABS farm water use statistics and was deemed to be sufficiently accurate for the purposes of this study considering that overall use of irrigation for grains production is small (3.7% of the cropping area in 2005/06) and it would be a complex and expensive task to create a more rigorous estimate.

Table 1: Wheat, barley and oats production in NSW in the year 2005/06 ('000 t) (Source: ABS)

Region	Wheat	Barley	Oats
Northern SD*	1,391	475	34
North Western SD	1,653	377	139
Central West SD	1,555	547	204
Murray SD	1,269	376	66
Murrumbidgee SD	1,890	527	145
South Eastern SD	273	18	42
NSW Total	8,049	2,336	633

* SD = Statistical Division

Table 2: Estimated volume of irrigation water used to grow cereals in NSW in 2005/06 ('000 ML)

Region	Total	Maize	Wheat	Barley	Oats	Triticale	Sorghum
Northern SD*	47.9	12.3	31.5	3.7	0.5	0	0
North Western SD	18.8	4.2	13.9	1.0	0.6	0	0
Central West SD	9.4	0.4	7.7	0.8	0.5	0	0
Murray SD	148.6	12.6	99.0	30.5	5.9	0.6	<0.1
Murrumbidgee SD	287.3	47.1	181.1	47.0	10.5	1.5	<0.1
South Eastern SD	0.1	0.1	0	0	0	0	0

* SD = Statistical Division

2.2. Virtual water content calculation

To make a comparison with existing literature, the virtual water content (VWC, l kg^{-1}) of wheat grown in NSW was calculated. Crop yields were obtained from the ABS statistics. Crop water use (i.e. the sum of evaporation and transpiration) was estimated using APSIM modelling of irrigated and dryland wheat crops to reproduce yields consistent with the ABS data at the level of the Statistical Local Area and using local soil and metrological data for the 2005/06 season. The VWC was calculated by dividing the crop water use by the crop yield. The production weighted average for NSW was subsequently calculated.

2.3. Water footprint calculation

Water footprints were calculated following the method of Ridoutt and Pfister (2010a). The inventory stage incorporated the consumption of blue water (appropriated from surface and groundwater resources), the required gray (or dilution) water (being the volume of freshwater needed to assimilate emissions to freshwater, Chapagain *et al.*, 2006) and the change in blue water availability arising from land use (i.e. through altered drainage and runoff). Each of these interventions is classified as limiting the availability of freshwater for the environment and/or other human uses. Blue water associated with irrigation is described above. Blue water is also used to manufacture farm inputs (e.g. fuel, fertilizer) and to supply farm services (e.g. farm advisory services, accountancy services). Data published by the Australian Bureau of Agricultural and Resource Economics (www.abare.gov.au) were used to determine the average expenditure per ha cropped by NSW farmers engaged in wheat and other cropping in the 2005/06 year. Water use was calculated using environmental input-output data (Foran *et al.*, 2005) and other sources. Where necessary, CPI multipliers were used to adjust financial data to the year 2005/06. Blue water use associated with the production of capital goods, such as machinery and buildings, were excluded from the assessment.

Nitrate leaching from the cropping system (kg ha^{-1}) was estimated using APSIM modelling at the level of the Statistical Local Area. The gray water requirement was calculated based on the US EPA's recommended limit for nitrate in drinking water of 10 mg l^{-1} (as nitrogen). The wheat, barley and oats cropping systems of NSW were assumed to have no negative impact on the availability of blue water resources as a result of land occupation.

Impact assessment: Local characterisation factors for freshwater consumption were taken from the Water Stress Index (WSI) of Pfister *et al.* (2009). The average Australian WSI was used in relation to farm inputs where the location of production was uncertain. The midpoint indicator values were then normalised by dividing by the Australian average WSI and expressed as Australian-equivalent water footprints using the units H_2Oe. This has been found to be useful for communication purposes as it enables a decision maker to quantitatively compare the pressure exerted on freshwater systems through the consumption of a product (i.e. via indirect freshwater consumption) with an equivalent volume of direct freshwater use.

3. Results and discussion

3.1. Virtual water content of Australian wheat

When the VWC was calculated for wheat grown in NSW, using APSIM modelling to reproduce yields consistent with the ABS data for the 2005/06 season and using local metrological records for this period, the production weighted average was 1234 l kg^{-1} (Table 3). This contrasts with previous published estimates for Australian wheat ranging from 1339 to

Table 3: Virtual water content (VWC, l kg^{-1}) of Australian wheat and the proportion of green (Gr) and blue (Bl) water consumed (%).

Reference	VWC	Gr	Bl
Oki and Kanae (2004)	2966	-	-
Chapagain & Hoekstra (2004)	1588	-	-
Aldaya *et al.* (2010)	1502	73	27
Hanasaki *et al.* (2010)	1339	96	4
This study: New South Wales	1234	97	3

2966 l kg^{-1}. The difference is largely explained by the crude assumptions about Australian wheat production made in the earlier estimates. For example, Chapagain and Hoekstra (2004) based their analysis on national average climate data, which for a large and climatically diverse country like Australia is unlikely to be representative of local growing conditions. Chapagain and Hoekstra (2004) also assumed that crop water requirements were always fully met, which is far from accurate in the Australian context. Aldaya *et al.* (2010) used data from the FAO Aquastat database which describes the cultivated area equipped for irrigation in Australia at 5.7%. However, for Australia, Aquastat does not describe the area equipped for irrigation that was actually irrigated. Nor does it specify the particular crops. In NSW, in 2005/06, by far the greatest irrigation water use occurred in the growing of cotton and rice. As such, we have concerns about the reliability of much of the published data relating to the VWC of crops and the associated arguments about sustainability. The underlying tenet of Chapagain and Hoekstra's (2004) work is that agricultural commodities should be sourced from countries and regions where they can be grown most water efficiently. On the basis of their analyses, Australia would appear to be a less preferred source of wheat as they estimate the global average at 1334 l kg^{-1}. However, our findings directly contradict this.

Furthermore we argue that the VWC of a crop is not a useful sustainability indicator because it does not differentiate the type of water used and the local water scarcity where production is occurring. A similar criticism can be made of water footprint calculation methods that result in a single value that is numerically equivalent to the VWC. For wheat grown in NSW in 2005/06, the VWC ranged from 1070 l kg^{-1} in the southern Murrumbidgee Statistical Division to 1333 l kg^{-1} in the Northern Statistical Division. However, what also needs to be taken into consideration is that irrigation water use for wheat production was far higher in the Murrumbidgee Statistical Division (181.1 compared to 31.5 ML, Table 2) and that local water stress is also much higher: WSI > 0.9 for the Murrumbidgee Statistical Division compared to WSI < 0.1 for the Northern Statistical Division. Irrigated cropping systems, especially if they are in high WSI locations, have the potential to cause environmental harm in ways that dryland systems generally don't. As such, information about the VWC of a crop is unlikely to inform wise decision making that will lead to more sustainable use of the world's freshwater resources and could even potentially lead to perverse outcomes. This issue is not unique to cropping. Similar problems arise in the comparison of pasture, rangeland and feedlot-based livestock production systems and their downstream meat products.

3.2. Water footprint of wheat, barley and oats grown in NSW

The Australian-equivalent water footprints (WF) for wheat, barley and oats grown in NSW in the year 2005/06 were respectively: 86.5, 80.7 and 65.4 l kg^{-1} H_2Oe (Table 4). In other words, the consumption of one kg of wheat, barley and oats grown in NSW in the year 2005/06 had an equivalent potential to contribute to freshwater scarcity (as defined by the WSI, Pfister *et al.*, 2009) as the direct consumption of 86.5, 80.7 and 65.4 litres of water in Australia. Freshwater scarcity is a useful focus for midpoint modelling because it is involved in all of the many cause and effect chains relating to damages from freshwater consumption. In this study, we have not proceeded to endpoint modelling, although the characterisation factors published by Pfister *et al.* (2009) make this possible. These Australian equivalent water footprints do not represent the absolute volume of water required to grow these cereal

Table 4: Australian equivalent water footprints (l kg^{-1} H_2Oe) for wheat, barley and oats grown in NSW. The components are also shown (%).

	Wheat	Barley	Oats
NSW average	86.5	80.7	65.4
Statistical Division			
Northern	3.15	2.19	3.70
North Western	2.73	2.16	3.05
Central West	12.26	4.56	7.82
Murray	182	190	210
Murrumbidgee	230	211	173
South Eastern	1.50	1.42	2.87
Components			
Irrigation	96.4	97.1	94.3
Gray water	2.2	1.1	2.0
Land use	0	0	0
Farm inputs	1.5	1.8	3.7

products. Although being of great interest to farmers and agronomists, the absolute volume of water needed to grow agricultural commodities is not correlated with the potential to cause environmental harm. In this study, the correlation between VWC and WF was negative. Whereas the absolute volume of water required to grow one kg of wheat, barley or oats in NSW may exceed 1000 litres, for communication to an Australian audience, the impact of that water consumption is more realistically compared to about 80 litres of direct water use. These product water footprints for wheat, barley and oats can be broadly compared to 31 l H_2Oe for Peanut M&Ms® (250 g bag), 350 l H_2Oe for Dolmio® pasta sauce (575 g jar) (Ridoutt and Pfister, 2010a) and 101 l kg^{-1} H_2Oe for Australian fresh mango (Ridoutt *et al.*, 2009a), noting there is variation in the scope and system boundary between these studies.

There was also substantial variation between Statistical Divisions. For wheat, the WF ranged from 1.50 to 230 l kg^{-1} H_2Oe, a 150-fold difference (Table 4), and clearly the WF is much more variable compared to the VWC. The variation in WF between Statistical Divisions was largely explained by varying use of supplemental irrigation and local WSI. For the year 2005/06, 8.8 and 10.7% of the cropping areas (all cereals excluding rice) were irrigated in the Murray and Murrumbidgee Statistical Divisions. By comparison, less than 2% was irrigated in the other Statistical Divisions. Across the State, irrigation accounted for the vast majority of the water footprint, 96.4% in the case of wheat, with emissions to freshwater and farm inputs making a minor contribution (2.2 and 1.5% respectively for wheat, Table 4). However, in regions using only minor amounts of irrigation, the water used to produce farm inputs made the largest contribution to the water footprint (Table 5). This has implications for the design of water footprint standards and product category rules.

Table 5: Factors contributing to the water footprint of cereals grown in the Northern Statistical Division of NSW, where only 1.8% of the cropping area was irrigated in 2005/06 (%)

	Wheat	Barley	Oats
Irrigation	45	22	23
Gray water	8	5	4
Land use	0	0	0
Farm inputs	47	73	74

4. Conclusion

This study has highlighted the importance of describing impacts rather than volumes in assessing consumptive water use in agri-food product life cycles. For cereals grown in the large Australian state of New South Wales, a 150-fold difference in water footprint was found between the major Statistical Divisions when the calculation method of Ridoutt and Pfister (2010a) was applied. This reflects variation in the use of supplemental irrigation and local water scarcity. The differences were much greater again when comparisons were made at higher levels of geographical discrimination, such as the Statistical Local Area. Critically, these differences were not evident when the VWC of cereals were compared. As such, we caution against the public communication of the VWC of products and water footprints which are calculated in such a way that they are numerically equivalent to the VWC.

In Australia, the vast majority of grains are produced without the use of supplemental irrigation and therefore with little potential to contribute to environmental water scarcity. That said we do not arbitrarily discriminate against irrigated agriculture. Water footprinting focuses on a single issue, namely the potential contribution of a product, product system or process to environmental water scarcity. Major strategic decisions should only be taken after considering all of the relevant impact categories as well as the broader triple bottom line concerns. While irrigated cropping systems have the potential to contribute to environmental water scarcity in ways that dryland systems generally don't, irrigated systems offer other advantages such as a greater resource use efficiency of land for food production.

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Practical issues of product carbon footprinting: experiences from Thailand

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ABSTRACT

Considering the huge concerns over climate change in Thailand and elsewhere in the world, carbon footprinting of certain food products was initiated in Thailand in 2008. The results of two case studies, one on chicken products and one on tuna, are presented. These initial case studies, the first in Thailand and probably in the world for chicken and tuna products using PAS2050 methodology, reveal the importance of conducting the carbon footprinting exercise as well as the limitations involved and the need for harmonizing the methodology especially for specific product chains. The development of product category rules is suggested as one possible solution to address the methodological issues.

Keywords: Carbon footprint, Chicken, Product Category Rules, Thailand, Tuna

1. Introduction

Climate change has been identified as one of the major challenges facing the world today and efforts are on worldwide to reduce the emissions of greenhouse gases (GHGs) which contribute to global warming. It has increasingly been recognized that emissions of GHGs are not only related directly to energy conversion (which no doubt is a major contributor), but also indirectly through the consumption of goods and services. This has raised consumer interest in information about the carbon footprint (life cycle GHGs) of products and services so that they can contribute to a reduction in emissions of GHGs through their consumption choices (Munasinghe *et al.*, 2009). To this end, many countries in the world have worked towards the promotion of carbon footprinting and labeling with the cooperation of environmentally-conscious organizations (Munasinghe *et al.*, 2009; Brenton *et al.*, 2008). Those include, *inter alia*, the UK, France, Germany, Spain, Switzerland and Sweden in Europe; Japan, South Korea and Thailand in Asia; and the US and Canada.

The focus on product carbon footprint and labelling activities has also contributed to raise concerns among producers and service providers about the possible consequences of these on their competitiveness. Countries exporting their products over a long distance especially perceive themselves at a disadvantage (Brenton *et al.*, 2008; Edwards-Jones *et al.*, 2009). To meet this challenge, initiatives have been made in several countries to build the capacity of industries for estimating the carbon footprint of their products. Food products have been a

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focus, firstly due to the early concerns related to 'food miles' and also due to the contribution of agriculture to non-CO_2 greenhouse gases (GHGs) such as CH_4 and N_2O (Edwards-Jones *et al.*, 2008; Garnett, 2008). Thailand, a major exporter of several products especially in the agriculture and food sector, has also started efforts in this direction. This paper describes the first attempts at carbon footprinting of food products in Thailand through a collaborative research project between Thailand and EU higher education and research institutes. The studied products were selected based on the export values of products to EU countries as well as the interests of pilot companies, which were chicken and tuna.

2. Methodology

At the time of the initiation of the study in late 2008, the most comprehensive product carbon footprint methodology available was the PAS 2050:2008 of the UK (BSI, 2008). Also, the UK is a major market for the studied Thai food products and hence this methodology was adopted for the carbon footprint analysis. This methodology was introduced to the pilot companies, especially the Guide to PAS 2050 (Carbon Trust *et al.*, 2008), to help them set the objectives for the carbon footprint, build the process map (life cycle diagram) and identify the internal team and the major suppliers that needed to be engaged in the footprinting process.

The process maps of the tuna and chicken chains are shown in Figures 1 and 2 respectively. For tuna, the product is solid tuna (white meat only) in sunflower oil. For the case of chicken, small pieces of chicken meat from special cutting processing (i.e. cutting and trimming of chicken parts) are used for producing “Chicken snack” by deep frying with vegetable oil. Both the products are sold to overseas buyers who then distribute it for retail. The system boundary for both cases thus stops at the distribution centre i.e. business-to-business. Use phase and waste disposal are not included. The units of analyses were set according to the form of product being sold to the business partners; thus for the chicken case study it was 4,200 kg (42 Oriented Polypropylene bags of 100 kg each in one jumbo corrugated box) and for the tuna case study it was 200 grams of tuna in sunflower oil (net weight; 150 grams of drained weight) in steel can. Economic allocation was used for both the studies as per the requirements of PAS2050.

For the tuna processing company, all the primary as well as secondary processing are performed within the company; however the tuna is purchased from suppliers. Thus primary data (input materials, energy use, output products and waste) were collected for tuna storage and processing at the company. However, secondary data on tuna fisheries had to be collected from suppliers based on fuel used by the fishing vessels and hauls per trip.

The chicken company is to a large extent vertically integrated with the feed producing companies, pullet farms, hatcheries, breeder and broiler farms all belonging to or having contracts with the parent company. Thus primary data (input materials, energy use, output products and waste) were collected at each of the facilities. Data at the farm level were collected for a representative set of farms (as the total number of farms supplying chicken was about 200). For raw material production such as feed ingredients (corn, cassava, etc.), secondary data were collected i.e. information of fertilizer application and crop yield from the Office of Agricultural Economics, Ministry of Agriculture, for the locally produced materials. For imported products such as soybean, literature sources were used. Detailed transportation data were collected as the information of routes and types of transport of various raw materials as well as fuel use for transport of products (intermediate and final) were available from the company. Packaging for both the companies was manufactured by suppliers who had very good relations with them, thus facilitating data collection.

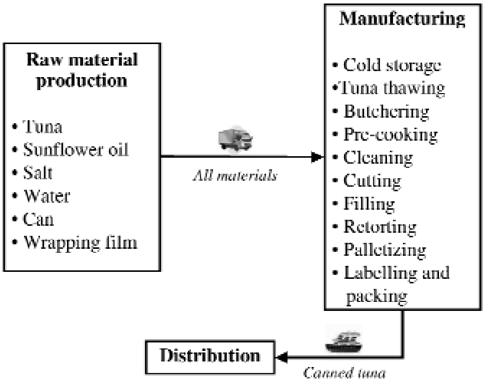

Figure 1: Process map of canned tuna in sunflower oil

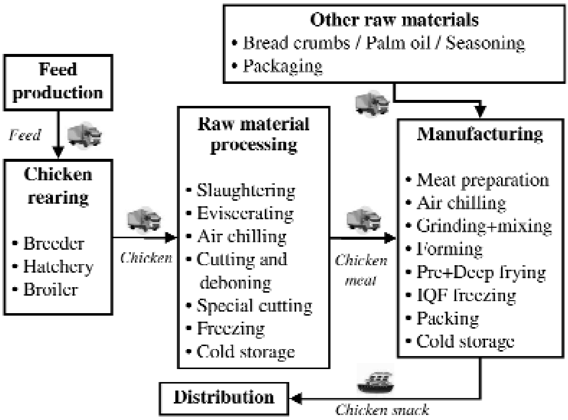

Figure 2: Process map of chicken snack

3. Results and discussion

3.1 Canned tuna in sunflower oil

Figure 3 shows that the largest contributions to the carbon footprint of the tuna product is from the raw materials which contribute almost half the total (tuna fisheries 37%, sunflower oil 12%), followed by packaging (steel can), and tuna processing. The tuna is largely obtained from the Indian and Western Pacific Oceans requiring large fuel usage. The steel can production contributes a large fraction of the overall footprint because recycling has not been considered; this would otherwise be significantly reduced. Sunflower oil is imported from Argentina thus increasing the carbon footprint. In the tuna processing steps, especially the retorting and pre-cooking are energy intensive processes which contribute more than 70% of the emissions followed by cold storage contributing another 10%. Transportation of the product to the UK by ship accounted for only 8% of the overall carbon footprint.

A major issue encountered was the collection of representative data for tuna fisheries as the tuna processors are buying the fish from intermediate suppliers who in turn are purchasing from many fishing companies that follow different routes based on availability of tuna. The processing companies thus have very little control over the actual fishing vessels.

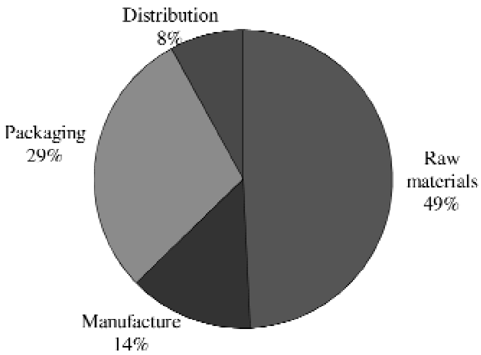

Figure 3: GHG emission contributions from the various phases of canned tuna in sunflower oil

3.2 Chicken snack

For the chicken snack, Figure 5 shows that the largest contribution to GHG emissions was from the manufacturing stage which contributed almost 60% – the major processes contributing to this stage are individually quick freezing (29%), followed by cooking and grinding-mixing (7% each), and storage (5%). The broiler farm contributes about 30% of the total carbon footprint out of which the rearing of broiler itself contributes about three fourths (mainly from feed production). Transportation of the product to the UK contributes only 5% of the overall carbon footprint. Packaging contributes less than 1% of the overall carbon footprint of the product.

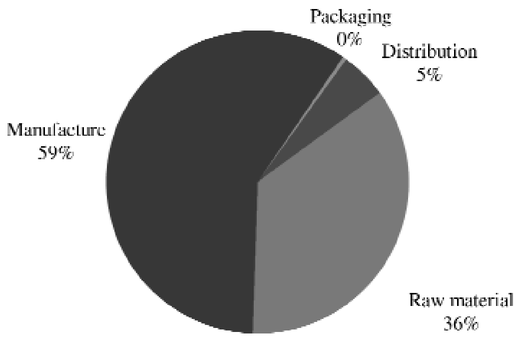

Figure 5: GHG emission contributions from the various phases of chicken snack

4. Conclusions

For the chicken product, the major share of the greenhouse gases is contributed by the broiler production and processing stages, whereas that for tuna by the fisheries and local processing. Packaging had a negligible contribution to the life cycle greenhouse gas emissions for the chicken product, but significant for the case of canned tuna. One of the major reasons for this is that the chicken product is in a bulk pack whereas the tuna is in a retail pack. However, use of recycled steel for the can or alternative packaging materials could be considered to reduce the carbon footprint of canned tuna (Hospido *et al.*, 2006).

Long-distance transportation of products to the consumers has often been perceived as a major source of greenhouse gas emissions which would affect the competitiveness of products exported from far-away countries. This, however, has not been found to be a significant issue in the products investigated in this study both of which are transported from Thailand to Europe.

A major methodological issue identified in the chicken case study was that of allocation in the processing lines due to the production of multifarious products with varying processing requirements. The issue related to the number of chicken parts (sometimes over a 100, relative sizes of which varied based on market demand) was compounded by the differences in prices of the parts which varied considerably both temporally as well as geographically (e.g. chicken breast has a high value in Europe whereas chicken feet have no value whereas the preference is reverse in many countries in Asia). Using economic allocation as per PAS2050 was not only difficult, but perceived as not appropriate by the industry. Another issue is that raw materials for feed production vary almost daily based on prices of each particular raw material; also, they are purchased from the open market and it is often quite difficult to trace back the source/farm.

For the tuna case, in addition to the difficulty in obtaining data on tuna fisheries as mentioned earlier, another practical issue was the huge amount of minor variations in ingredients due to varying customer demands leading to problems with definition of product. Using the standard company definition of Stock Keeping Unit (SKU) might not always result in a large variation of carbon footprint for different SKUs. It was discussed whether the threshold of carbon footprint score could be considered for product definition, for instance, SKUs with less than 1% difference in carbon footprint can be counted as a single product. Possible solutions to these issues were identified in consultation with the industrial partners which may be useful for the definition of sector guidelines or product category rules (PCRs)[1].

The concept of PCR development for chicken and tuna was well agreed by the industry to ensure the consistency and comparability of carbon footprint results. However, there is a great concern attached to the national life cycle inventory databases that might not be as developed as in other countries and could become a barrier to conduct carbon footprint studies at a large scale in the future. The industry was also concerned about the understanding of consumers on carbon footprinting and labelling. A carbon label without the carbon footprint value but just to indicate the company's commitment to reduce GHG emissions could be a key for wider acceptance and implementation from the production side. For the consumption side, public relation activities are essential to inform the consumers about the impacts on climate for them to include this as one of the considerations in their purchasing decisions.

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[1] PCRs are sets of specific rules, requirements and guidelines for developing Type III environmental declarations for one or more product categories (BSI, 2008)

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