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The carbon dioxide emission footprint of food products and their application in the food system

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Summary

The research reported has developed a method for calculating carbon dioxide (CO2) emissions from food products using recipe and farm production data. The method has utilised published Life Cycle Inventory (LCI) CO_2 emission measurements for the production of crop and livestock ingredients. These measurements are complemented by conversions of energy use for drying, milling and baking of these ingredients to CO_2 emissions. The results presented show that CO_2 emissions associated with primary production are greater than processing and manufacturing emissions. Emissions associated with distribution and packaging can be relatively low if efficient design and logistics systems are implemented. These data suggest greatest improvement in resource efficiency is likely to be identified at crop production levels in the food supply chain. Livestock products are more CO_2 intensive than plant products, however, products containing plant oils can significantly increase CO_2 emission intensity of a recipe. These data are developed to explore the relationship between CO_2 emissions and other greenhouse gas emissions.

Key words: Food manufacture, carbon dioxide, supply, carbon footprint

Introduction

The food production sector will become increasingly accountable for the environmental impacts associated with distributing food to customers. Assessment of the environmental impact of food and beverage products is increasingly highlighted as a challenge for the food and beverage sector (Defra, 2006*a*). An important goal for the food and beverage sector is to identify a method of impact assessment for CO_2 and total Greenhouse Gas (GHG) emissions (as CO_2 equivalent) that can be applied to a range of specific food products. There are a number of methods to assess environmental impacts of manufactured products and these vary in complexity and outcome. Proven methodologies such as Life Cycle Analysis (LCA) and the implementation of Environmental Management System (EMS) approaches have helped to define food system boundaries (Defra, 2007). LCA research data for the agricultural production system is well characterised (Cowell & Clift, 1995; Küsters, 1999; Tzilivakis *et al*., 2005; Casey & Holden, 2006; Williams *et al*., 2006, Danish Environmental Protection Agency, 2007). Specific LCA and LCA-based studies have been reported for horticultural produce (Danish Environmental Protection Agency, 2003; Defra 2006*a*; HRI, 2007), livestock products (Casey & Holden, 2006), and transport (Defra, 2006*b*). The reported assessments have not used food recipes as the functional unit for the analysis and have taken food chain system-wide approaches. A method for calculating CO_2 emissions for food will be highly relevant to current policy and New Product Development (NPD) in the food and beverage sector.

The research presented here is a CO_2 accounting method for supply chain CO_2 emissions, further research is currently considering how to include nitrous oxide and methane emissions in recipe-based scenarios.

Methods

Carbon footprint for farm production of food ingredients

Measurement of CO_2 emissions for intensive arable production provide typical values of 1500 kg CO_2 ha^{-1} (Cowell & Clift, 1995; Küsters, 1999), intensive livestock production results in typical values of 4000 kg CO_2 ha^{-1} (Casey & Holden 2006) and production of root crops results in typical values of 1500 kg CO_2 ha^{-1} (Tzilivakis et al., 2005). The actual figures can vary between 900–1700 kg CO_2 ha^{-1} depending on crop yield obtained. The relatively high emissions figure of 1500 kg CO_2 ha^{-1} is used in the research reported here as a constant for the primary production footprint of plant-derived ingredients in the reported calculations (Equations 1 and 2). A future toolbox approach for the methods reported here will provide a means for specific crop yield and emission values to be introduced into calculations.

Yield of farm products

The yield of agricultural crops have been obtained from Defra statistical publications (Defra, 2006*c*) and UNFAO statistical databases (FAOStat, 2007). The emissions associated with ingredients from livestock products have proved difficult to quantify because of the dynamic nature of stocking rates. The results reported here use livestock conversion factors (Imhoff *et al.*, 2004). These are grain equivalents of 2.3 kg of grain for 1 kg of carcase, 2.2 kg of grain for 1 kg eggs and 0.3 kg grain for 1 kg of milk. We have divided average wheat yield in the UK (8 t ha^{-1}) by the livestock conversion factor. This is multiplied with the scaled weight of livestock products in recipes to provide livestock product CO_2 emission for that ingredient which can be directly related to a typical wheat emission value of 1500 kg CO_2 ha^{-1} (Equation 1).

Equation 1
Grain Equivalent Yield for livestock products (GEY)

$$= \text{Wheat yield } (8 \text{ t grain ha}^{-1})/\text{LCF}$$

where LCF = Livestock Conversion Factor (Imhoff *et al*., 2004)

This conversion method relates well to CO_2 emissions for dairy and beef production (Casey & Holden, 2006; 2.3 × 1500 = 3450 kg CO_2 equivalents ha^{-1} t^{-1} of live weight). The CO_2 emission t^{-1} ingredient for crop products can be directly calculated by dividing 1500 kg CO_2 emissions ha^{-1} by the reported yield statistic (Equation 2). This was multiplied by the scaled weight of crop product ingredients in recipes. A similar approach is used for livestock products using the GEY (Equation 2).

Equation 2

CO_2 emission t^{-1} ingredient

$$= PC/ (Y \text{ or } GEY)$$

where PC (Primary CO_2) = 1500 kg ha^{-1} carbon dioxide emission associated with a hectare of crop production. Y = reported yield of specific crop (Defra, 2006*c*; FAOStat, 2007)

Milling, baking and drying CO_2 emissions for food production

Typical electricity and gas costs relate to July 2007, there will be significant changes in these values but the relationship of power to CO_2 emissions will remain constant.

For milling, the calculations have used a figure for a typical flour mill processing 200 000 t grain yr^{-1} with an electricity bill of £500 000 yr^{-1} or £2.50 t^{-1} to mill which is 25 kWatt hour t^{-1} milled at 10 p kW $hour^{-1}$. Using Enworks (2007) conversion figures for kW hour (electricity at 0.43 kg kWh^{-1}) into mass of CO_2 this is equivalent to 10.8 kg CO_2 t^1 wheat milled. Emissions associated with milling are assumed to be equivalent to the emissions associated with cutting, grinding etc. for other ingredients except water.

For baking, a typical bakery is considered to use 2500 t of raw material each year with a gas bill of £200 K yr^{-1} which is £0.80 t^{-1} to bake or 32 kW hour t^{-1} at 2.5 p kW $hour^{-1}$. Using Enworks (2007) conversion figures for kW hour (natural gas at 0.19 kg kWh^{-1}) into mass of CO_2 this is equivalent to 6.1 kg CO_2 t^{-1} of product baked. Emissions associated with baking are allocated to all ingredients.

Drying has been reported to emit 23 kg CO_2 t^{-1} for crop materials and grain (Mortimer *et al.*, 2004). Emissions associated with drying have been allocated to all ingredients except water.

Thus, for secondary production (milling, baking and drying) of products in this study the calculation for obtaining CO2 emissions is described in Equation 3.

Equation 3

mg CO_2 emission g^{-1} product in Secondary Production (SP)

$$= (wt\ (g) \times 10.8) + (wt\ (g) \times 6.1) + (wt\ (g) \times 23)$$

Transport CO_2 emissions for food

CO_2 emissions for the transport of food ingredients over 1 km are reported in this paper. The data used for this is derived from published diesel consumption figures (Küsters, 1999) of 0.016 L km^{-1} t^{-1} by truck and 0.0078 L km^{-1} t^{-1} by coastal ship. We have converted fuel consumption using a constant of 2.68 kg CO_2 L^{-1} of diesel (Enworks, 2007).

Equation 4

µg CO_2 emission km^{-1} g^{-1} product in transport

$$= (wt\ (g) \times 42.88) \quad \text{Truck}$$
$$= (wt\ (g) \times 20.90) \quad \text{Coastal ship}$$

Results

Where recipes are used to collate emissions on a per ingredient basis (Tables 1 and 2), then these can be used to calculate summary data for a range of products (Table 3). Table 1 shows a typical recipe for a pork pie. The amount of primary production associated CO_2 emissions for this recipe is 79 g CO_2 kg^{-1} of recipe. The drying, milling and baking CO_2 emissions associated with the pork pie recipe are 30 g CO_2 kg^{-1} of product. Table 2 shows a typical recipe for a fruit flapjack. The amount of primary production associated CO_2 emissions for this product is 229 g CO_2 kg^{-1} of product. This is relatively higher than in Table 1 because of the high oil content of the recipe. The drying, milling and baking CO_2 emissions associated with the fruit flapjack product were 40 g CO_2 kg^{-1} of product.

Table 1. *Recipe for a typical pork pie and the CO_2 emissions for production of ingredients on farm using an LCF for livestock products and published national yield data*

Pork pie filling Ingredients	Amount (g)	Y or GEY t ha^{-1}	g CO_2 per ingredient and product
Onion	250.00	38.00	9.87
Pork	700.00	3.48	301.88
Sausage	300.00	3.48	129.38
Egg	200.00	3.64	82.50
Milk	100.00	26.67	5.63
Chicken stock	1000.00	3.48	21.56
Lard	1000.00	3.48	21.56
Water	2500.00	0.00	0.00
Flour	4000.00	8.00	37.50
Salt	50.00	0.00	0.00
Pastry			
Flour (g)	1010.00	8.00	189.38
Lard (g)	252.50	3.48	108.89
Butter (g)	252.50	26.67	14.20
Total	11615.00	128.38	922.35

Table 2. *Recipe for a typical fruit flapjack and the CO_2 emissions for production of ingredients on farm using an LCF for livestock products and published national yield data*

Fruit flapjack Ingredients	Amount (g)	Y or GEY t ha^{-1}	g CO_2 per ingredient and product
Brown sugar	800.00	50.00	24.00
Butter	600.00	26.67	33.75
Margarine	400.00	1.50	400.00
Oats	2500.00	5.00	750.00
Salt	10.00	0.00	0.00
Fruit	1000.00	15.00	100.00
Golden syrup	500.00	30.00	25.00
Total	5810.00	128.17	1332.75

Table 3. *Summary of CO_2 emissions associated with sandwich and cooked hot meals for production of ingredients on farm and processing using the methods described*

Food product	g CO_2 crop production per 100 g product	g CO_2 processing per 100 g product
Tomato, pepper mozzarella salad	10.00	3.93
Roast ham and cheese		
White sliced bread	28.00	4.00
Granary sliced bread	27.27	4.09
Vegetable korma	5.63	3.99
Meat and potato pie	14.74	3.20
Chunky vegetable and spinach risotto	4.78	3.26
Mushroom and spinach lasagne	6.28	3.99

Discussion

A typical analysis for primary production data is shown in Table 1 for a pork pie batch recipe. The emissions are relatively low due to high water and flour content of the recipe. The CO_2 emissions associated with drying, milling and baking (secondary production) emissions are 2.99% of the final product weight. The omission of water and salt from the calculations presented is the subject of further research. The CO_2 emissions associated with secondary production and processing are generally 2.5–4% of the product weight. Table 2 shows the CO_2 emissions associated with a fruit flapjack with 23% of the product weight being primary production CO_2 emissions. This is a higher figure than the pork pie livestock product shown in Table 1 because the increased use of plant oils and no use of water in the recipe. Sandwich products have higher CO_2 emissions because they often have a range of complex ingredients including livestock, vegetable and oil products in combination (Table 3). Food products prepared in batch such as pies, breads and stews (in Tables 3) have lower CO_2 emissions than sandwich products. This is because water is usually a large component of these recipes.

The CO_2 emissions given in Tables 1–3 are lower than reported CO_2 equivalent emissions that include nitrous oxide and methane. We are currently investigating the relationship between livestock feed, associated GHG emissions and conversion into livestock product (Smil, 2002). The results presented in Tables 1–3 do not account for distribution, preservation or business transaction emissions at present. In order for a realistic CO_2 equivalent assessment to be made of the food system preservation and waste functions will need to be quantified in further research.

The CO_2 emissions associated with transport in this study were uniform for individually sold food products (e.g. sandwiches) at around 43 mg CO_2 km^{-1} kg^{-1} of product. This reduced to at 33 mg CO_2 km^{-1} kg^{-1} for recipes produced in batch because water distribution emissions are not included. Published LCA data (Franklin Associates, 2006) suggest figures for CO2 emissions associated with packaging are 115–185 mg CO_2 g^{-1} packaging material. If these figures are placed in a catering scenario with effective waste management planning they could be extremely low.

Conclusion

It is likely that awareness of supply chain impacts associated with agricultural produce will become increasingly considered by consumers to be an important aspect of purchase choice. Furthermore, an understanding of the CO_2 equivalent emissions associated with food will provide insights into efficient supply and energy use within businesses.

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