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Product carbon footprint of rye bread

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ABSTRACT

The primary purpose of this paper is to estimate the carbon footprint of conventional rye bread produced on an industrial scale and consumed in Denmark by identifying the stages that contribute significantly to the carbon footprint (hotspots) of production. The results are then interpreted by comparing and discussing the results of this study with the results of other studies identified in the extant body of literature. To estimate the carbon footprint, we considered an industrial bakery supply chain in a single in-depth quantitative case study. Using an attributional approach, we estimated the carbon footprint of 1 kg of rye bread to be 731 g CO_2 equivalents (CO_2eq). As in previous studies, the primary hotspot was found to be the raw material stage, especially agricultural production (cultivation), with processing and distribution stages as secondary hotspots. The waste management stage was determined to be an important and previously overlooked opportunity for improvement.

1. Introduction

Growing concern for climate change among company stakeholders has triggered increased interest in and relevance of estimating greenhouse gas (GHG) emissions of products (Cellura et al., 2012; Notarnicola et al., 2012; Seuring and Müller, 2008). For this reason, product carbon footprints (PCF) are of great interest as a central measure of environmental impact in supply chains (Čuček et al., 2012). By applying PCFs, companies can estimate the total GHG emissions emitted along the entire supply chain, from cradle to grave (Cappelletti et al., 2010). Numerous studies have assessed the environmental impact associated with consumption of food products, advancing the knowledge base about the environmental impact of food products (Tukker et al., 2006; Schau and Fet, 2008; Notarnicola et al., 2012). This research contributes to the course of research in two ways. First, although bread is among the food products with the lowest environmental impact, it remains a staple and important food product that is consumed in large amounts and in many countries (Braschkat et al., 2003; Roy et al., 2009; Espinoza-Orias et al., 2011; Kulak et al., 2012). For instance, in the Nordic countries, consumption of bread products has been linked to tradition and food culture, with Finland and Denmark having a strong tradition of baking sourdough rye bread (Nordic Ecolabelling, 2013). Second, interest in comparing the results between PCF studies is increasing from a research perspective, but has generally been fraught with difficulties (Schau and Fet, 2008; Udo de Haes and Heijungs, 2007; Pulkkinen et al., 2010). This paper contributes to research through a comprehensive review of life cycle assessment (LCA) and PCF studies of bread by comparing the results across the literature with the findings of this study. The next section provides an outline of the extant body of literature.

2. Product carbon footprints for bread products

Several researchers have studied the environmental impact of bread production. A search of the literature revealed 15 studies published since 1999 that support Pulkkinen et al.'s (2010) finding that many LCA or PCF studies have been carried out in the last 10 years. A brief summary of the studies is presented in Table 1.

2.1. Bread product

Various bread products have been studied, including white, wholemeal, and rye bread, as well as mixtures of these types. As shown in Table 1, studies tend to emphasize white or mixed bread (11 studies), with only three studies specifically assessing rye bread products (Nielsen et al., 2003; Grönroos et al., 2006; Saarinen, 2012). For instance, by estimating the GHG emissions along the supply chain until 1 kg each of white bread and rye bread reaches

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the retail market, Nielsen et al. (2003) found rye bread to be associated with slightly lower GHG emissions (790 g CO_2eq), as compared with white bread (840 g CO_2eq).

2.2. Production method

Similar to other studies of food products, a distinction is made between conventional and organic production methods, which basically refers to how the crop was cultivated and treated (Roy et al., 2009; Hokazono and Hayashi, 2012; Schäfer and Blanke, 2012). It is no surprise that previous studies have tended to emphasize conventionally produced bread (all 15 studies), although Braschkat et al. (2003) and Grönroos et al. (2006) also included an assessment of organically produced bread. According to Braschkat et al. (2003), organically produced bread has a lower carbon footprint (368 g CO_2eq, on average), as compared with conventionally produced bread (565 g CO_2eq, on average) and requires less energy use (see also Grönroos et al., 2006). This difference is explained as conventional cereal production requiring production of mineral fertilizers that are not, or only to a limited degree, used in organic cereal production (Nordic Ecolabelling, 2013). These results suggest that organically produced bread is a better option, from the perspective of GHG emissions, but organic production does not always result in lower environmental impacts (Department for Environment, Food and Rural Affairs [DEFRA], 2009b; Notarnicola et al., 2012; Salomone and Ioppolo, 2012). The same applies when comparing conventional and organic cereal production: it is difficult to decide which one is "better" due to large variations and uncertainties, especially when modeling highly complex organic production systems (Nordic Ecolabelling, 2013).

2.3. Production scale

Previous studies have compared emissions associated with bread produced on different scales, such as industrial production, local bakery or shop, and home baking. While most studies have focused on industrially produced bread (13 studies), Andersson and Ohlsson (1999), Braschkat et al. (2003), and Swedish Institute for Food and Biotechnology ([SIK] 2009) focused on comparing bread produced on different scales. For instance, Andersson and Ohlsson (1999) estimated the GHG emissions associated with bread manufactured on an industrial scale, a local bakery, and home baking. Their results indicate industrially produced bread as the option most likely to have the highest GHG emissions and home baking as the option with the lowest emissions. In contrast, Braschkat et al. (2003) identified industrially produced bread as resulting in the lowest GHG emissions, as compared with local bakeries and home baking. In addition, the more recent study by SIK (2009) identified that bread from local bakeries is associated with the lowest GHG emissions, as compared to industrially produced bread or home baking. This disparity indicates ambiguity in the results in terms of the GHG emissions associated with bread produced on different scales.

2.4. Geographical scope

A typical distinctive characteristic of bread production is the geographical region in which production occurs (Iriarte et al., 2010; Ruviaro et al., 2012). Bread has been studied in different national contexts, but the studies have all been conducted in Europe, with the only exception being Narayanas-Wamy et al. (2005), who studied bread production in Australia. The earliest study identified was performed in Sweden (Andersson and Ohlsson, 1999), while more recent studies were undertaken in the UK (Espinoza-Orias et al., 2011; Kingsmill, 2012; Sarrouy et al., 2012). The national context clearly has an impact on the PCF. For instance, Espinoza-Orias et al. (2011) studied how the origin of wheat (e.g., in the UK, Canada, France, Germany and USA) influences the PCF and identified that sourcing locally or nationally (i.e., in UK) produced wheat may be preferred, as compared to imported wheat, with respect to product quality.

2.5. Life cycle methodology and system boundary

By grouping the 15 studies based on publication date, it was noted that previous (pre-2006) studies are generally not explicit about their life cycle methodology and tend to define their system boundary "from cradle to retail/ready for consumption," thereby excluding the consumption and waste management stages. This exclusion can be explained, in part, because defining the system boundary as "from cradle to grave" requires estimating the actual (or average) use of the product, as well as subsequent recycling or disposal of the product after its useful life (McKinnon, 2010). This explanation is similar to Finkbeiner (2009), who argues that including the use phase might be controversial, both from a business-to-business (B2B) and business-to-consumer (B2C) perspective. However, given the increasing recognition of the importance of conducting integrated studies of the environmental performance of entire food production systems (Notarnicola et al., 2012), some of the more recent (post-2009) studies of bread products include environmental impact along the supply chain from cradle to grave.

2.6. Climate impact

Surprisingly large ranges exist for the PCF of bread, with results varying from 256 to 2300 g CO_2eq/kg bread. According to Pulkkinen et al. (2010), this difference is explained by methodological choices, type of energy used, and climate conditions. The carbon footprint is generally lower in earlier studies, as compared to more recent studies, with the only exception being Narayanaswamy et al. (2005). Specifically, studies targeting from cradle to retail/ready for consumption found that production of white bread on an industrial scale results in approximately 675 g CO_2eq/kg bread on average, while studies limited to from cradle to grave yielded results of approximately 1425 g CO_2eq/kg bread on average (see Table 1).

2.7. Hotspots

Studies generally identify cultivation of crop as the dominant in the PCF, and thus label it as the primary hotspot. Here, emissions of nitrous oxide (N_2O), a strong GHG, from agricultural land have a significant climate impact (Nordic Ecolabelling, 2013). Establishing sustainable agricultural systems, therefore, is an important aspect of the development of sustainable food supply chains (Notarnicola et al., 2012). In addition, the bread manufacturing and consumption stages are generally identified in studies as the second and third most significant contributing stages, with the only exception of Andersson and Ohlsson (1999), who identified transportation as the second largest contributor. However, this result is most likely due to Andersson and Ohlsson (1999) having included consumer transport to retail stores, which are excluded in later PAS-compliant PCF studies (Publicly Available Specification [PAS] 2050, 2011). Although transport is integral in the life cycle of many products, this is generally not the case in studies of fresh bread products (Nordic Ecolabelling, 2013).