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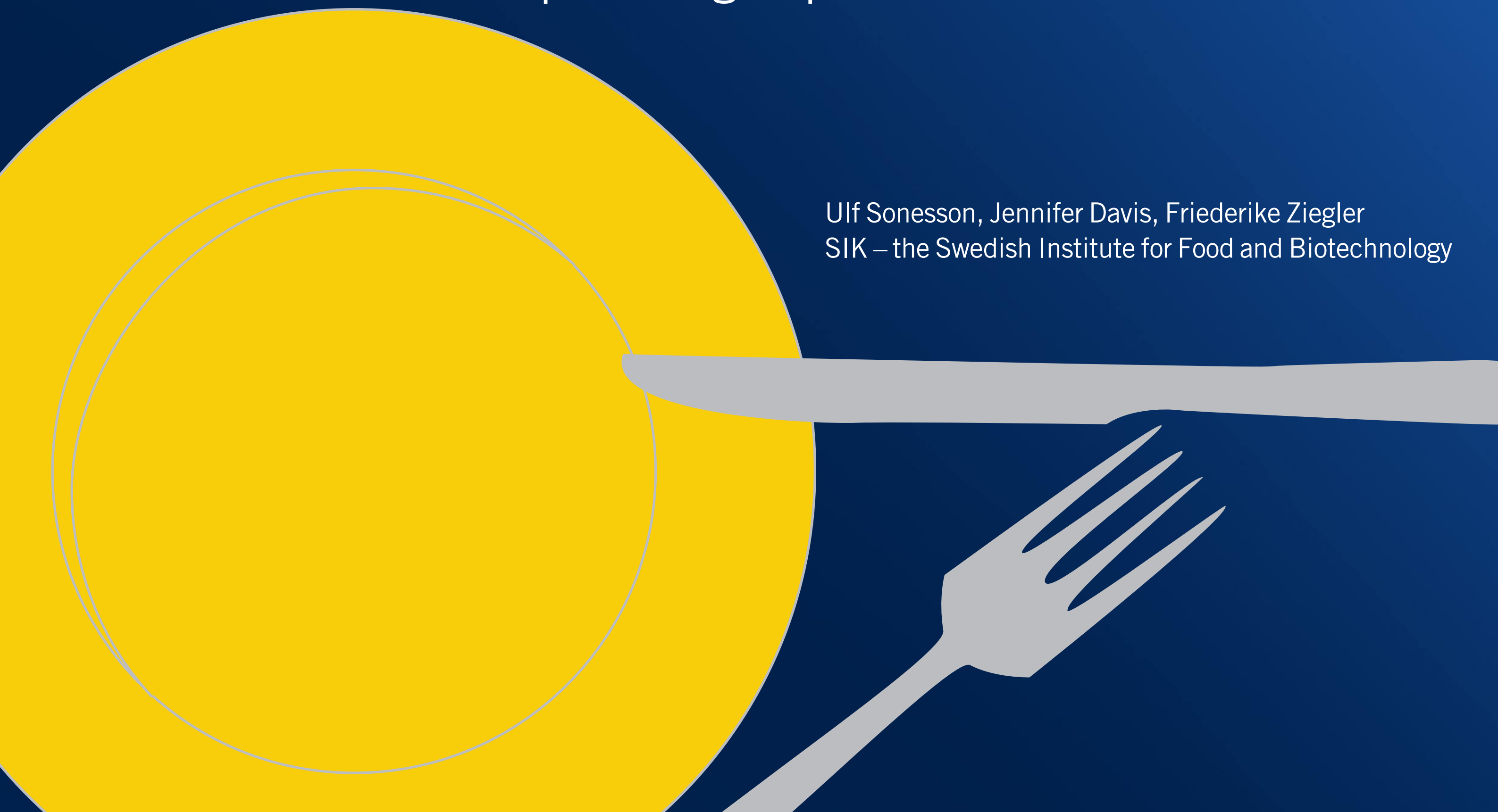
Food Production and Emissions of Greenhouse Gases

An overview of the climate impact of different product groups



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Foreword

The Conference Climate Smart Food is held in Lund 23-24 November 2009 and is organised by the Swedish Ministry of Agriculture. A report has been commissioned from SIK – the Swedish Institute for Food and Biotechnology: ”Food production and emissions of greenhouse gases - An overview of the climate impact of different product groups” .

The report provides an overview of the climate impact of different product groups and of the different stages of the food chain. Hence it will provide some factual background to the conference presentations on climate smart food choices, climate labelling and the potential to reduce emissions from the different stages of the food chain. It will also serve as a background to the discussions at the Conference.

The report is not concerned with the policy perspective although it points to some areas where mitigation potential may be found. It does not necessarily represent the official view of the Swedish Presidency.

Introduction

Food chains around the world are responsible for a large share of total emissions of greenhouse gases (GHG's). There are no studies presenting the share for the global food production system, but as an indication, Steinfeldt et al. (2006) reported that 18% of global GHG emissions could be attributed to animal products alone. For the EU, a figure of 29% of all consumption derived GHG emissions are food related (EIPRO, 2006). The latter study analysed the whole life cycle for all goods consumed within EU, i.e. including all imports and excluding goods produced within the EU and exported.

Food's climate impact in brief

Food production systems as a group are very heterogeneous, the range of products is huge and production systems vary within product groups as well. However, there are some common traits. To start with, emissions of fossil carbon dioxide (CO_2) are less important than for most other products, instead emissions of biogenic GHG's are more important. For vegetable products, nitrous oxide (N_2O) are often the most important emission, as well as for production of monogastric animals (pork, poultry), whereas for ruminants methane (CH_4) is often the dominating gas emitted. Methane and nitrous oxide are very potent GHG's, methane having a weighting factor of 25 times CO_2 and nitrous oxide 298 (IPCC, 2007). For seafood products, correlation between energy use and climate impact is higher, especially for wild-caught fish. The climate impact of products from capture fisheries is dominated by fossil CO_2 emissions from fuel use on fishing boats.

Products of animal origin, such as meat and dairy, have on average higher emissions per kilogram than vegetable products, but there are many exceptions. Transports play a role, but often smaller than anticipated. However, if less efficient transport modes are used, as air freight or inefficient distribution to grocery stores, transports can be of significance also in a life cycle perspective. An important share of food's life cycle impact is caused by the consumers, in developed countries the transport from the grocers' by car is very inefficient, and globally cooking can play an important role. Food waste ending up in landfills are also an important contribution to GHG emissions, methane is formed when food is degraded under anaerobic conditions in landfills. Packaging can be of significance, but it is a trade-off between functionality of the packaging as protecting the food and emissions of the packaging material.

Food production demands land, and fertile land is a scarce resource. Hence a high land use per unit food produced, i.e. low yield, is negative even if the direct emissions for the product are low. This is a result of the fact that if the yield were higher the land could have been used for alternative production such as biofuels or forest. It must also be kept in mind that how the land is used has significant impact on other environmental impacts, as eutrophication and biodiversity. Land use is also crucial for important aspects as valuable ecosystem services; provision of drinking water and clean air. How land is managed is also important for the GHG budget of food products. By employing farming methods that conserve soil carbon, farmland can become a carbon sink while still producing food.

A severe impact of food production is deforestation. In the report from Steinfeldt et al. (2006) around one third of the 18% of GHG's allocated to animal production is due to emissions caused by deforestation, especially in developing countries. A large share of global deforestation is driven by need for more arable land, especially in South America where soy cultivation and beef production is expanding.

Food chains are often complex with many interdependent actors, and increasingly also spans geographically large areas. Moreover, the products are often perishable which increase the complexity in maintaining environmentally efficient food chains. As a result of the above, losses in food chains can be significant. Wasted food means that all emissions caused and resources used are in vain; wastage contributes to the problems but not to food supply.

In the industrialised world there is an ongoing debate about organic versus conventional production about what production system is most "climate friendly". To describe it simplistically, the proponents of conventional farming use arguments of production efficiency per hectare whereas advocates of organic farming highlights the more resilient way of farming as an important aspect in the larger context. Important activities are similar between the two production systems, although absolute levels of impact differ, but since there is no general trend with organic production always being more efficient than conventional, we do not distinguish between them is this report. In short, there are differences in absolute numbers, but the key issues are similar. Basic knowledge about food production's climate impact can guide improvements in both production systems.

Methodological basis for the report

The basis for this description of food productions climate impact is mainly based on research within Life Cycle Assessment (LCA). LCA is an ISO standardised method for environmental assessment of products or services (ISO, 2006a, 2006b). In short LCA can be said to include all environmental impact caused by a product, from "cradle-to-grave" which means that all flows necessary to produce, process and deliver the product is included in the analysis. Within LCA, methods for transforming emissions of single substances into environmental impact categories are used. Examples of impact categories are climate change, eutrophication, acidification and toxicity. For resource use the methodology is less developed but resources as energy, land, water and minerals are included in LCA results. Production systems generally are complex with a lot of interdependencies with other technical and natural systems. Methods for defining systems boundaries and allocation of environmental burdens between products are slightly open, so results from LCA studies of similar systems can vary. This is not a result of one of them being wrong, but that different methodological choices have been made. Consequently results from LCA's must be interpreted as having uncertainties, but still very useful for identification of the most important parts of the system and also for identification and evaluation of improvement potentials.

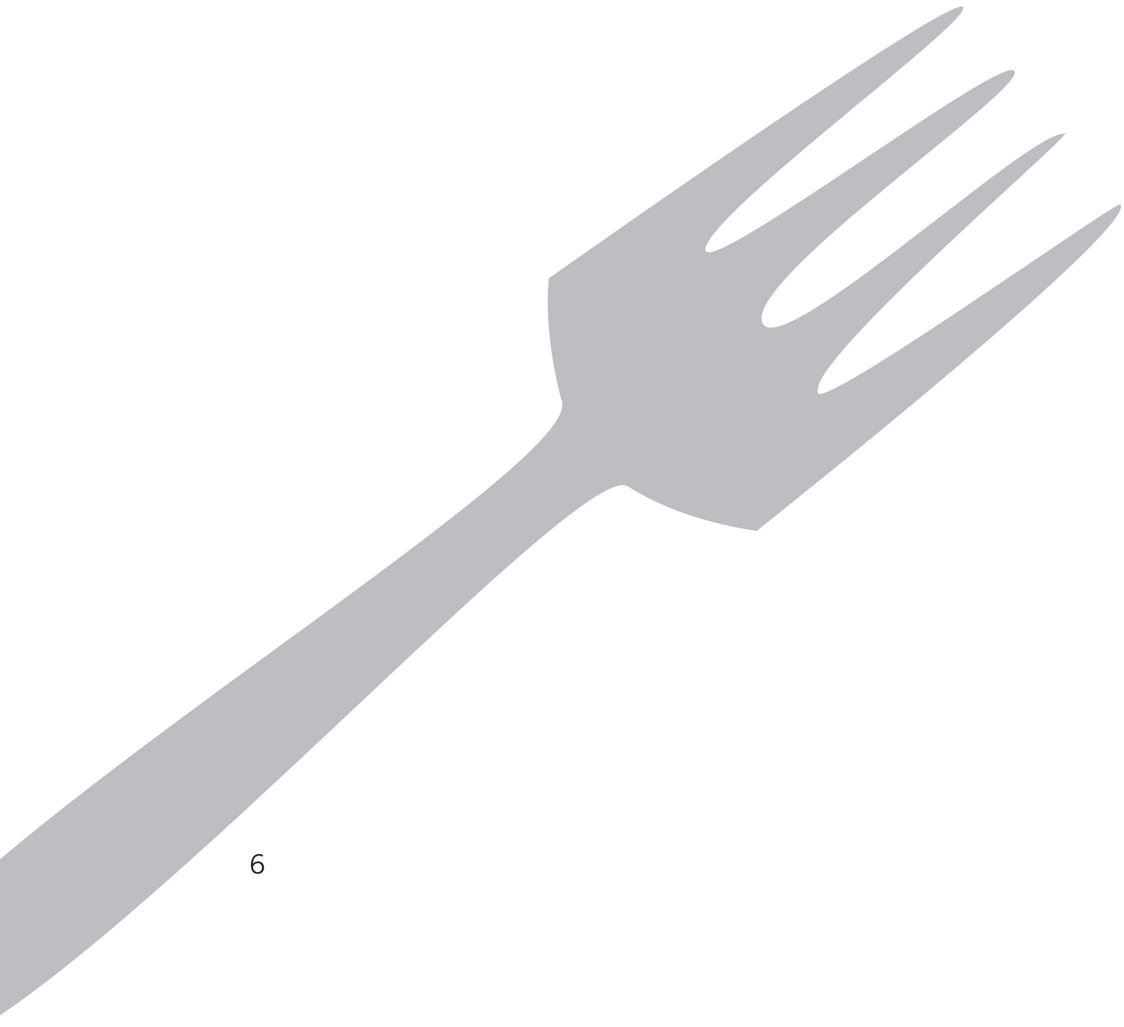
In food chains, the earlier parts (primary production and processing) of the chain differ significantly between product groups, whereas latter parts are more similar. Hence the first part of the report covers primary production of different product groups, and the second part covers post-farm activities of all product groups together.

Delimitations

This report describes food production's emissions of greenhouse gases. Food production affects our environment in many ways; eutrophication of waterways, acidification, spreading of toxic chemicals in pesticides, biodiversity and emissions of GHG's. Moreover, the cultural landscape in many parts of the world is depending on food production. We are certainly aware of this and strongly recommend that a broader spectrum is used when discussing sustainability of food systems.

Greenhouse gas emissions from land use change (LUC), most importantly due to deforestation, are not covered in this report, data availability is limited and methodological issues on how to allocate deforestation emissions to products needs to be resolved.

A final important notion is that the mix of products we choose to consume, our diet, is a very important parameter for the total climate impact of food consumption. By changing diets on a large scale long term improvements can be gained, but with large consequences for all actors in the chain. To discuss and implement diet changes a good understanding of how production systems work is essential, it is not either or but both. In this report we present the production perspective while acknowledging the importance of diet choices.



Greenhouse gas impact from different product groups

Meat and Dairy Products

To discuss emissions of GHG's from animal products, we need to divide them in two groups, monogastric animals and ruminants. For monogastric animals as pigs and poultry the feed provision is the most important activity, followed by manure management. The emissions are dominated by nitrous oxide (N_2O) from soil turnover of nitrogen and emissions from production of mineral fertilisers. Energy use can be of significance for some animals as chicken in cold climates where houses have to be heated during winter, and in warm climates where houses have to be cooled. For ruminants, as cattle, sheep and goats, emissions of methane (CH_4) are often the most important. Most methane originates from the enteric fermentation, i.e. when feed is digested in the rumen; a minor share comes from manure management. The second most important emission is nitrous oxides from nitrogen turnover in feed production and manure management. Generally emissions from manure management are more important in warmer climates, since the processes generating GHG emissions are stimulated by higher temperatures. For all animal products later steps in the chain as transport, processing and packaging are less important, in a relative sense.

Beef

Beef are produced in extremely different production systems globally, but also within countries and regions. Beef is either produced in "dedicated" beef herds, where beef is the only main product, or as a co-product from dairy production, i.e. bull calves from dairy herds are raised for beef and culled cows are used for meat. The common picture from all these varied systems is that methane from enteric fermentation (feed digestion) is important for the life cycle GHG emissions. When ruminants consume feed, micro-organisms in their rumen degrade the cellulose and hemicelluloses into substances the cattle can utilise. In this process, which is anaerobic, methane is formed by the micro-organisms and emitted. The ability to utilise roughage feeds is not only negative, from a resource point of view ruminants can make use of lands where only grass can be grown, hence can be said to valorise non-edible feeds to high quality food.

In systems where a large share of the feed is concentrated, as grain and soy, the emissions for feed provisions increases, both nitrous oxide and CO2. At the same time, the methane emissions are lower if concentrate feed is used, but the balance is not clear. Since emissions from biological processes in the rumen are important, it is vital that the growth of cattle is high in order to have low emissions per kg of meat. If animals grow very slow, a lot of methane is produced from the digestion of feed needed to maintain the animals' life, without producing any meat. Along the same line of reasoning an important explanation to the high GHG emissions for beef is the slow regeneration rate. Cows give birth to at best one calf per year, which means that all emissions during one cow-year have to be carried more or less by the meat produced by the calf. In combined dairy-meat production systems the cow produces both milk and a calf every year which makes beef from such systems less emission intense.

There are a number of LCA studies from different regions, results for global warming and energy use are summarised in Table 1, to give an overview. It should be noted that the studies presented can not be compared directly. There are differences in methodology, as allocation between hides, meat and milk and sometimes the system boundaries differ slightly. Moreover, the weighting factors for methane and nitrous oxide was changed by the IPCC in 2007 (IPCC, 2007), which make results from older studies slightly lower than results from newer studies. Moreover, some studies are based on one or a few farms, others on farm modelling and still others on national averages. The latter (Cederberg et al., 2009a, b and Verge et al., 2008) have a tendency to show higher results, partly since more flows are covered than in the other two types but mainly due to changed weighting factors for methane introduced in 2007.

Table 1. GHG emissions for beef reported in different studies

Study	CO_2-equiv./kg bone-free meat				MJ/kg bone-free meat
	Total	*CH_4*	*N_2O*	*CO_2*	
Ogino et al. (2007) Japan	32	23	2	7	
Casey & Holden (2006a, b), Suckler, Ireland	28-32				
Williams et al., (2006), ”Average UK beef”	16				28
Williams et al., (2006), ”100% suckler”, UK	25				41
Verge, et al., (2008), ”Average Canadian beef”	30	15	11	4	
Cederberg et al. (2009a), ”Average Brazilian beef”	40	31	9	0	5
Cederberg et al. (2009b), ”Average Swedish beef 2005” [a]	28	17.5	7	3.5	
Cederberg & Darelius (2000), ”Swedish beef from combined systems dairy-beef”	17-19	9-10	5-6	3	44

[a] *64% of the meat originates from combined dairy-beef production (surplus calves and culled cows).*

Dairy

The GHG emissions from dairy production are similar to that of beef production, enteric fermentation and manure dominates with a contribution of 50-60% and nitrous oxides from feed production and manure management contributes with around 30% (Sevenster & de Jong, 2009). There are however differences, dairy farming in developed countries are generally more intense with a larger use of concentrate feeds as grain and soy. As a consequence feed provision is slightly more important.

The milk yield per cow is a determining factor. Using a slightly technical perspective it is important to have as large share as possible of total feed intake (and methane emissions) being used for producing milk as opposed to the animal using a large share for maintenance. It is important to include also the feed and time needed to raise the calf. Conclusively, the yield must be balanced with the risk of having shorter productive life for the average cow.

Milk is one of the products being most extensively analysed by LCA. There are a number of studies from Europe and New Zeeland, very few (if any) from developing countries. The results are rather similar, and varies between 0.8-1.4 kg CO_2-equiv./kg milk at farmgate. In addition around 0.1 for processing and transports up to retail is presented (Sevenster & de Jong, 2009, a report summarising the findings from a large number of LCA studies in the field of dairy products). Since milk has high water content (around 88%) it is reasonable to consider that in comparisons with other animal products. Normalising milk to 70% water means the emissions of GHG's is between 3.1 and 3.8 kg CO2-equiv./kg, on a similar dry matter basis as meat (still other properties differ).

Pork

Pigs are monogastric animals and only produce very small amount of methane in their feed digestion. But pigs can not utilise cellulose and hemi cellulose in feeds, but need to be fed grains and alike, feed that could be used directly as food by humans. The life cycle emissions are normally dominated by agriculture and inputs to it, the later steps in the chain are less important, besides unnecessary wastage.

As can be seen in Table 2, emissions of GHG's from pork are lower than for beef, and production is dominated by nitrous oxide. Since no methane is formed in the feed digestion, the feed provision is the most important parameter, and accounts for between 60-70% of total emissions up to farm gate (Cederberg & Darelius, 2001, Strid Eriksson et al., 2005, Cederberg et al., 2009b, Basset Mens & van der Werf, 2003). Feed provision includes emissions caused by production of fertilisers, soil emissions of nitrous oxides and energy used in

Table 2. GHG emissions for pork as reported in different studies

Study	CO_2-equiv./kg bone-free meat				MJ/kg bone-free meat
	Total	*CH_4*	*N_2O*	*CO_2*	
Williams et al., 2006	5.6-6.4				14-17
Basset Mens & van der Werf (2003) [a]	5.3-8.0				37-42
Cederberg & Flysjö (2004),	4.1-3.6	1.1	1.6-2.1	0.9-1.2	15-18
Strid Eriksson et al. (2005) [b]	3.2-3.5				13-16
Cederberg m.fl. (2009b) [c]	5.2	1.3	2.6	1.3	

[a] The results have been recalculated from "Live weight" to "bone-free meat" using a yield factor of 43%

b Only the fattening phase was included, not rearing of piglets

[c] The results have been recalculated from "Carcass weigh" to "bone-free meat" using a yield factor of 59%

arable farming. The remainder of emissions is mainly manure management, energy use for animal husbandry being a minor part. In warmer climates manure emissions is probably more important, since more methane are formed at higher storage temperatures. The results presented in Table 2 can not be directly compared due to differences in methodology.

Besides the differences in feed digestion, pork cause lower GHG emissions than beef due to a higher feed conversion and also the fact that one sow can produce up to 25 offsprings yearly; hence the sows' environmental impact is shared by many producing animals, i.e. the slaughter pigs.

Poultry

The only LCA studies of poultry concern chicken, no studies of duck, geese or turkey is presented. Since chicken is the absolutely dominating type of poultry globally as well as within the EU this is still relevant. Chickens are, as pigs, monogastric animals, and have a high feed efficiency. At the same time chicken have high demands on feed composition e.g. high demand on protein, both quality and quantity, which in turn puts high demands on feed production. The high feed efficiency is the explanation to the relatively low emissions of GHG's, the proportion of feed consumed by the chicken used for growing versus maintenance is high. In temperate and cold climates barns have to be heated, and depending on what energy source is being used the emissions vary. For example, in Sweden biofuels as straw or wood chips is the most common fuel used, whereas in most other parts of the EU fossil fuel is dominating. In a sensitivity analysis presented in Tynelius (2008), the total emission of GHG's is increased with around one third if biofuels were replaced with fossil oil. In warmer climates cooling of barns can be an important contributor, but no studies including this have been found.

Seafood

Since the 1950s, fishing has seen considerable technological development on all levels and has progressed from an industry making small-scale use of certain wild fish stocks to become a large scale industrial operation that is highly efficient in localising and utilising wild stocks. The seafood market is one of the most globalised markets, in part due to the seasonality in supply, the huge variety in products and qualities and the described general lack of raw material experienced by the seafood processing industry driving it to

Table 3. GHG emissions for chicken as reported in different studies

Study	CO_2-equiv./kg bone-free meat			
	Totalt	*CH_4*	*N_2O*	*CO_2*
Thynelius, 2008 [a]	1.5			
Pelletier (2008) [b]	2.6			
Cederberg et al. (2009b) [c]	2.5	0.1	1.2	1.2
Williams et al. (2006), conventional [c]	6.1			
Williams et al. (2006), free-range [c]	7.3			

[a] Emissions per substance was not presented

[b] The results have been recalculated from "Live weight" to "bone-free meat" using a yield factor of 54%

[c] The results have been recalculated from "Carcass weight" to "bone-free meat" using a yield factor of 77%

new sourcing strategies and markets. Fresh and frozen seafood is therefore flown, shipped and trucked all around the globe. The demand for seafood is projected to continue to increase over the coming decades both due to growth of the world population and economic growth in new regions (SOFIA 2008). In this perspective, achieving more sustainable production systems for seafood products is urgent.

Fisheries

The climate impact of fisheries is dominated by carbon dioxide emissions from onboard diesel combustion, which is directly related to the amount of fuel used. The second major factor is the leakage of refrigerants from onboard cooling equipment if the refrigerants used have a high climate impact. Analysing the entire production chain from fisheries to fish consumption, it is the fishing phase that accounts for the greatest share of total energy utilisation and climate impact through onboard fuel combustion during fishing in modern, industrialised fisheries (Thrane 2004, 2006; Ziegler et al. 2003, Ziegler and Valentinsson 2008; Ziegler et al. 2009).

A number of factors affect the climate impact per kilo of fish landed, perhaps the most significant are fishing gear and species biology (Thrane 2006, Tyedmers 2001, Tyedmers 2004, Ziegler et al. 2003, Ziegler and Valentinsson 2008; Ziegler et al. 2009). The stock situation is another key factor that affects fuel efficiency. Low-density fish stocks mean that more time is required to accumulate the same catch compared with the same fish stock at a higher density, using the same gear. It is difficult, if not impossible, to fish an over-exploited stock in an energy-efficient manner. In other words, in addition to the fishing method, the stock situation is a key factor in determining the energy efficiency of fisheries (Schau et al. 2009).

Aquaculture

The climate impact of seafood products from aquaculture is often dominated by production of fish farm inputs, most importantly the feed (Tyedmers et al. 2007, Pelletier & Tyedmers 2007). Filtrating mussels that are farmed require no feed input, as opposed to farmed fish. Some fish (such as carp, tilapia, and pangasius) are omnivores and can survive without animal-based feed ingredients, which means they can normally be fed using agricultural products or residues. Other species, including those that have become very popular recently, salmon, trout, and cod, are predators that require some input of marine-based feed, i.e. in industrialised production systems a combination of fishmeal and fish oil (Troell et al. 2004; Pelletier and Tyedmers 2007; Findus 2008; FHL 2009).

What about the role of the supply chain after landing? Seafood is one of the most traded food commodities globally, so transports can play a role. The demand for fresh fish means that some fish is air freighted which has severe consequences for total emissions of GHG's, this is discussed in more detail in following sections. Since seafood is perishable, cooling or freezing is needed which add to GHG emissions. Otherwise, the proportion of frozen seafood products total emissions of GHG's represented by transport is typically under 20%, which is showed in several studies (see references above).

Vegetable products

Grains

The climate impact of grains is fairly well investigated. Even though there are some differences in the impact between different grain and energy crops, mostly depending on the yield level, there is a common pattern of what the most important aspects are when it comes to emissions of GHG's. First, the production and application of nitrogen fertiliser is a very important contributor to the overall climate impact of these products. Production of nitrogen fertiliser generates fossil CO_2, but also, and more importantly, nitrous oxide. Moreover, when the fertiliser is applied, nitrous oxide is emitted both directly when applying the fertiliser and indirectly as a consequence of ammonia release and leakage of nitrate. Secondly, the use of diesel for agricultural operations (ploughing, harvesting etc) and for drying the produce results in CO_2 emissions. As an example, Figure 1 shows the magnitude of GHG's from the production of wheat flour produced in the south of Sweden; here it is quite evident that nitrogen fertiliser is the dominant source of GHG's, a result of the emissions of CO_2 and N_2O from production of the fertiliser and the direct and indirect emissions of nitrous oxide when applying it. It should be noted that the results presented is from a mill using hydropower and had short transport distances both for raw materials and ready products, hence it is probably a very efficient system from a GHG perspective.

One of the most important foods globally is rice. There are two main production methods, dry ("upland") and wet ("paddy") rice. Production of upland rice is similar to other grain crops from a climate impact perspective, so this section focuses on paddy rice which is also the most important production form globally. The specific issue with paddy rice is that methane is formed under the anaerobic conditions in the flooded fields. There are few LCA studies on rice, but on a global level it is reported that rice accounts for 10-13% of global methane emissions (Neue, 1997). Blengini & Busto (2009) presents an LCA of Italian paddy rice, and although Italy is not a large rice producer globally, some of the findings have general bearing on paddy rice production. The total emissions of GHG's are 2.9 kg CO2equiv./kg of white milled rice, which is in the order of six times higher than the wheat flour presented in Figure 1. The main difference is the field emissions, mainly methane, amounting to around 70% of total emissions. But also a high use of fossil energy for processing contributed to the difference.

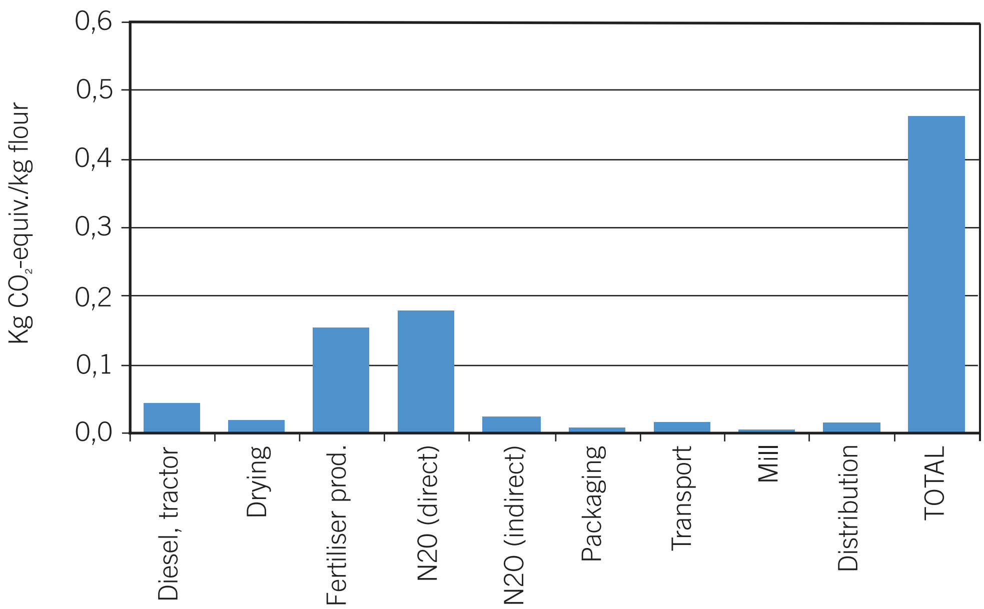


Figure 1. The significance of different stages in the life cycle of flour produced in Sweden, from farm to delivery at the retailer (based on Cederberg et al. 2008)

Grain Legumes

Grain legumes, such as peas, fava beans and soy beans, are efficient sources of protein compared to animal protein, i.e. they do not require the same amount of inputs per kg protein as compared to the inputs required to produce 1 kg of animal protein. Grain legumes' ability to fixate nitrogen from air means that only small, if any, nitrogen fertiliser is applied in the cultivation, which of course benefits the climate profile of these products. There are a few studies assessing the impact of grain legumes, e.g. Lagerberg-Fogelberg & Carlsson-Kanyama (2006) which compared beans and peas with different origin as well as different types of processing (drying, canning). The study showed that the cultivation, i.e. use of diesel, is an important contributor to the total GHG emissions of the product, and that for canned products the packaging also plays an important role. Another study, by Davis et al (2009), which compared meals with varying protein sources (similar content of protein, fat and energy), showed that a meal with a pea burger is associated with significantly less GHG's compared to a pork chop meal (see Figure 2). However, this study highlighted the need for efficient processing of products with vegetable protein such as veggie burgers, since these products are often sold frozen due to small stock units, which can result in high energy costs for freezing and frozen storage.

Fruits & Vegetables

In general, the production of fruits and vegetables are associated with fairly low emissions of climate gases. As for grains, the most significant aspects of GHG's sources are use of diesel and nitrogen fertilisers, as well as yield level. Potatoes and other root vegetables are particularly efficient in the cultivation, since the yield level is so high per ha, resulting in low emissions of GHG's per kg product. However, depending on soil type the emissions can vary; cultivation on peat soils results

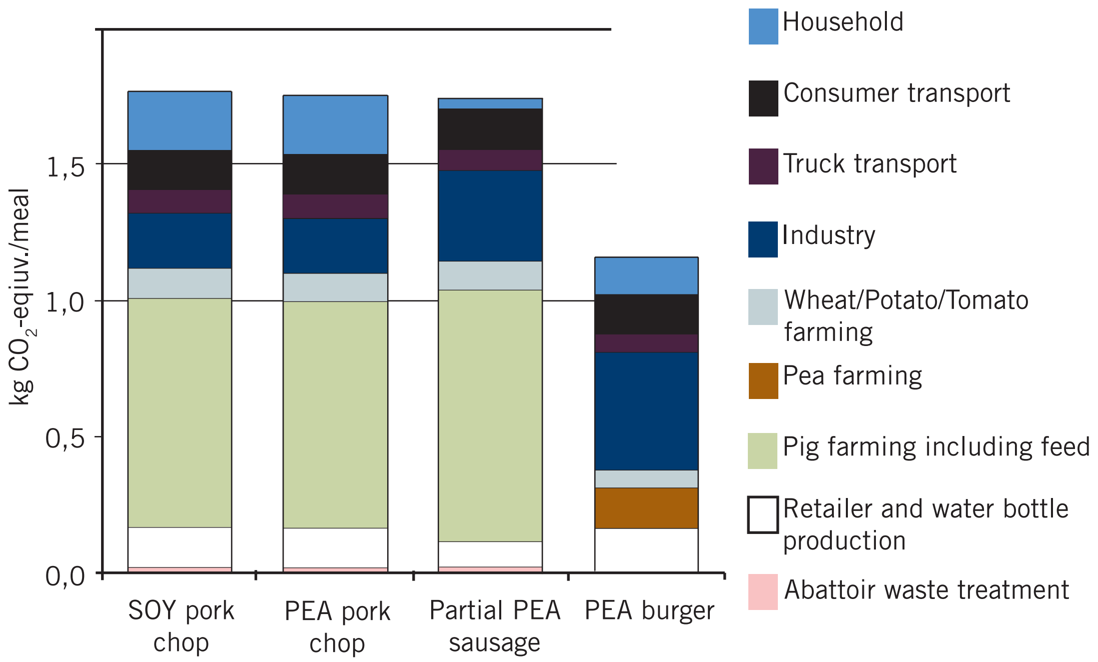


Figure 2. A comparison of the climate impact (kg CO2equiv./meal) of different types of meals (production and consumption in Spain). Davis et al. (2009)

in quite significant losses of CO_2 and nitrous oxide from the soil. Nevertheless, because the cultivation typically is efficient, i.e. low inputs and emissions per produced unit, the importance of downstream processes is higher in relative terms. This means that production and waste handling of the packaging, as well as processing and transport, are often important contributors to the overall carbon footprint for these types of products. For products grown in heated greenhouses, the type of heat production is the most important parameter for the product's carbon footprint, where of course use of fossil fuels result in high emissions of GHG's. A switch to renewable fuels alters the picture, even though this does not eliminate the need for more efficient heating in the greenhouse, to save energy. Figure 3 illustrates how the choice of heating affects the carbon footprint of tomatoes, where a fossil based heating system results in more than three times higher emissions of GHG's than from tomatoes grown in a greenhouse heated with biofuel. Cultivation in Spain does not require any heating; the contribution from the example in the figure predominantly comes from soil emissions of N_2O. The figure also shows the scale of difference between cultivation on mineral and peat soil, giving an example of cultivation of carrots where growing on peat soil gives considerable emissions of CO_2 from the soil.

Another important environmental aspect when it comes to fresh fruits and vegetables is that these types of products are often sensitive to handling and have limited storage time, which can result in significant quantities of wastage. The wastage means that unnecessary environmental impact has occurred when producing the food item if it is just thrown away, and moreover, further environmental impact might follow when treating the generated waste. This is discussed more in the following sections.

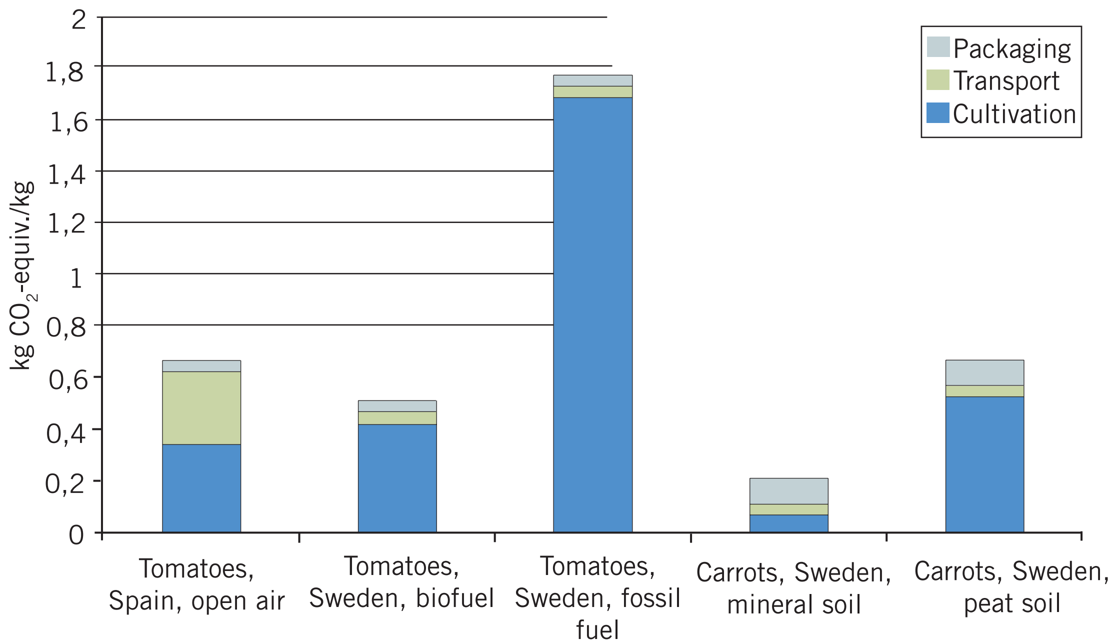


Figure 3. Climate impact (kg CO2equiv./kg product) of tomatoes and carrots consumed in Sweden (preliminary data from ongoing project at SIK, to be published in 2010)

Transports, Packaging, Retail and Consumption

As mentioned earlier post farm activities are of less significance for animal products but more for vegetable products. The absolute impact for e.g. a certain transport per kg of product is similar regardless of product group, but since there are so large differences in emissions of GHG's from primary production the relative importance of transports, packaging and consumption for product groups differ.

Transports

The food sector is transport-intense; a lot of inputs to food production as well as food products themselves are transported in large volumes and sometimes long distances. This can sometimes be of great significance for the total life cycle GHG emission of a product, but often transports contribute relatively little in a life cycle perspective. There are some important aspects when discussing transports. One thing is the transport mode, what type of vehicle is used. For some high value, perishable foods airfreight is used, but for most foods truck, rail or sea transport is the most common. These transport modes differ significantly in energy intensity and hence GHG emissions. The GHG emissions for different transport modes varies between close to 2 kg CO_2equiv./ton*km[1] for regional air freight to 0.01 kg CO_2equiv./ton*km for container ship. This is a simplification, for many reasons. Foods often needs refrigeration which increases the use of energy and also introduces leakage of refrigerants into the GHG emissions equation (refrigerants are often high in climate impact). Foods are often, but not always, high volume goods, so the maximum load is not determined by weight but volume, so fewer tons can be transported by one truck, which increases the emissions per ton*km. Finally, distribution of foods from warehouses to retail stores are often less efficient, slow driving with a lot of stops combined with low load factor. The last link in the transport chain, between retail stores to households are probably the least efficient, at least for industrialised countries were a significant percentage of these transports are performed by car.

A simplified summary of food transports are that they become less efficient the longer down the supply chain you get. So, transports of feed and other agricultural impacts are often very efficient, high density, often by ship, train or large lorries and rarely refrigerated. Transports from farms to industry are often slightly less efficient since some products are perishable. The next step, from industry to warehouses or retail entails high volume and low weight goods and to some extent less efficient distribution. The last step, consumers' home transports is the least efficient; if cars are used, small loads (typically 10-20 kg per trip) using a vehicle weighing more than 800 kg indicates a very low efficiency. It can be argued that food shopping is done in conjunction with other errands; hence the food shouldn't carry all responsibility for the emissions, which make sense. There are few studies on consumer behaviour in relation to food shopping, but Sonesson et al. (2005) found that in Sweden, more than 60% of shopping trips were made using car, around 50% of these trips were made with the sole purpose of food shopping, so food shopping are an important driver for car use in Sweden at least. The outliers in the above description are products being air freighted, where the airfreight itself use a lot of energy per ton*km.

Food Wastage

Food is wasted in all nodes in the food chain. Data on what percentages of food being wasted in different parts of the world are scarce, no overview is found. According to Stuart

1 The unit ton*km represents the work needed to transport one ton one km

(2009), who summarised a vast volume of data from literature combined with own investigations, the possible savings amounts to 33% of global food supply, meaning that 33% of food produced is avoidable waste, globally.

Reasons for wastage differ, but many foods are perishable by nature. Other reasons are lack of co-ordination along the supply chain, inadequate packaging and storage conditions and finally consumer's lack of meal- and purchase planning. In agriculture most wastage is due to harvest and storage. In industry food is wasted due to cleaning but also production planning, which in turn depends on lacking coordination along the supply chain. Since some food products carry a heavy "climate backpack" when entering the industry (notably products of animal origin), reduced wastage is often the most efficient improvement potential for food industries. This has been demonstrated in several studies of the dairy industry (Berlin et al. 2007, Berlin & Sonesson, 2008, Berlin et al., 2008). As an example, the GHG emission caused by raw material production of milk being wasted at the dairy was 33% of the dairy' total emissions (Berlin & Sonesson, 2007). For food of animal origin the wastage might not be as important as primary production on a per kg base, but vegetable products, especially vegetables and fruit show large losses, and the waste management might cause considerable emissions. If food waste is being put into landfill large quantities of methane is formed.

In industrialised countries it is a well known fact that large volumes of food are being wasted by households. This is based on waste statistics, what products are being wasted is less clear. From a study performed in the UK wastage of different product groups were presented (Ventour, 2008). The results showed that there were large differences between product groups, with "salad greens" at the top with 45% of purchased products being wasted, followed by bread with 31% and fruits with 26%. At the other end of the scale we find dairy products (3%) and meat- and seafood (13%). The figures represent "avoidable waste", i.e. excluding peels, kernels etc. There are few other studies on household waste, but Sonesson et al. (2005) presents figures for some products being in the same range as the ones mentioned above.

Retail

The retail sector's direct impact on total life cycle GHG emissions is often limited. In retail, energy use, mainly for freezers and refrigerators, and refrigerant leakage are the most important sources for direct emissions, but probably more important are the emission caused by wastage in the sector. The retail sector also has an important role in the coordination of activities in the food chain, being placed between the consumers and producers.

Packaging

Food packaging is often thought of as a bad thing for the environment, with excessive use of plastics and paper. However, packaging has important roles to play in the food chain; it protects the food thus keeping it safe and healthy. But packaging also reduces wastage, which is very important from a climate point of view, and packaging can be used to transform information along the supply chain which facilitates efficiency improvements. What type of packaging being used influences the transport efficiency since it has its own weight but also affect the weight/volume ratio of the product. So, the climate impact of packaging is a trade-off between the positive function (reduce wastage, facilitate communication) and the negative impacts (increased volumes and weight to transport, emissions caused by production and waste management of packaging materials).

Consumption

The most important impact from the consumer stage in the chain is already covered, wastage and home transports. But cooking can also be an important contributor to total life cycle GHG emissions, especially for vegetable products (with low emissions in earlier stages) that require long boiling times.

Improvement Options and Potentials

This section gives a brief overview of improvement potentials. It is not possible to present in-depth descriptions of improvements for the large and varying product group foods.

Primary Production

A key issue in decreasing climate impact of foods from agriculture is nitrogen turnover. To produce nitrogen as mineral fertiliser cause GHG emissions, soil turnover of nitrogen and manure management as well. So, if less nitrogen is wasted, less needs to be produced and fewer emissions will occur from nitrogen “at the wrong place”. Nitrogen use can be optimised in arable farming by more accurate application, in animal husbandry by reduced emissions from manure storage and spreading but also through optimised feeding.

By using land management that increases the content of organic content in soils, a globally important carbon sink can be created. Good land management, i.e. maintaining soil fertility is a second key issue since it facilitates high yields which in turn are important for a climate- and economic efficient agriculture.

In fishery one of the most efficient improvements are maintaining or re-building fish stocks. By this more fish can be caught with less effort, hence less fuel is used per ton of fish. Deploying more energy efficient fishing methods, or avoid the most energy intense, is also important. Generally passive gears (set nets, traps) are more energy efficient than active gears such as trawls. To phase out synthetic refrigerants is also an efficient measure. In aquaculture improvements can be made by optimising feed use, both by less wastage and higher biological utilisation and by using less resource demanding feed ingredients, e.g. avoiding use of feed fish that are caught in energy demanding fisheries.

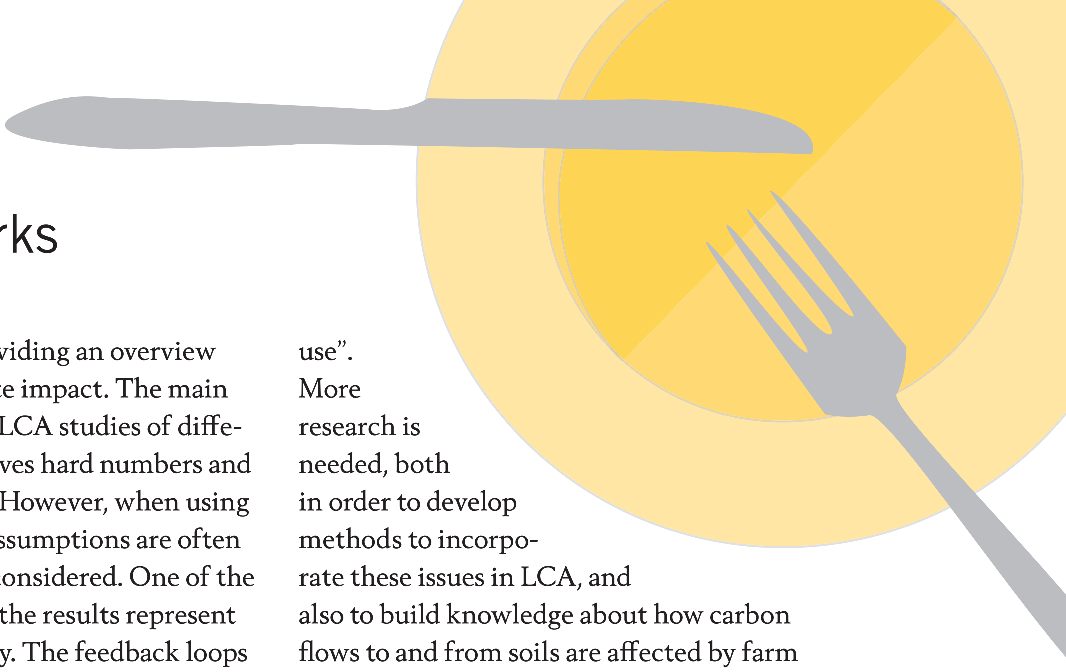
In the Food Chain as a Whole

In the post farm food chain, raw material utilisation is a key issue. By minimising waste, fewer raw materials is needed to provide the same amount of products, thus reducing the need for arable land which can be used for other purposes. Wastage can be reduced by technical means as better storage conditions, but a lot can be done within food industry by working with “lean production” concepts. Improved shelf life with maintained or better product quality by novel processing technologies is another means to reduce wastage, both at retail and households. Packaging is an area where there are trade-offs between function and environmental impact, and specific considerations are needed for specific products. Generally, it is possible to reduce "over-packed" products or to avoid heavy and voluminous packaging. For some products, as yoghurt, around 8% of the product might still be left in the container when the consumer judges it as empty (Berlin et al., 2008). By good packaging design the possibility to empty the package is increased, hence wastage is reduced. Introduction of efficient recycling of packaging material is also positive.

There are several possibilities to improve the "climate efficiency" by working in a food chain perspective. By increased transparency in the supply chain, i.e. information flows with useful information between nodes, wastage can be significantly reduced by better match between consumer demand and production. In this field the retail sector has an important role.

Climate Labelling – Principles and Possibilities

In recent years climate labelling has been proposed as a means of reducing food's climate impact, by empowering consumers to make informed choices and hence put pressure on producers. There are two different principles in climate labelling, "declarations" and "criteria based". Climate declarations, often referred to as "Carbon Footprinting", build on quantitative data which is presented on the package, sometimes combined with information about whether the figure is high or low in comparison with other products. The climate labelling introduced by Tesco in the UK is a declaration labelling. Criteria based labelling use the same principle as eco-labelling; a set of criteria is described for each product or product group, and if the producers fulfil these criteria they are entitled to label their product. There are strengths and weaknesses with both principles. Declarations make it possible to compare products from different product groups, as meat and beans. At the same time declarations demands high quality analyses of the products, and this is costly. More important, declarations build on life cycle assessments (LCA), and the methodology and standards for performing LCA is open to different choices, and detailed knowledge about biogenic emissions is lacking, and hence results can differ for that reason. Moreover, the variations between farms and years pose another complicating factor. A second weakness is that quantification requires detailed data from actors in the food chain, and since they are stakeholders as well, third party verification becomes necessary. Even if the present work on standardisation is successful and the problem of verification can be resolved, there will still be large uncertainties about data quality etc since the analysed systems are large, complex and varying over time. In summary, climate declarations are efficient since they directly show the emissions and also since they leave open for the producers to improve their production in the most efficient way, not delimited by production based criteria as in criteria based labelling. But there are severe practical and methodological constraints. Criteria based declarations are easier to implement and check, there is no need for calculations. To identify and describe criteria is difficult and demands high level competence on systems level about food systems. The major drawback is that criteria labelling doesn't inform consumers about differences between product groups, it can in general only inform about what product in the category is better than other within the same category. Moreover, criteria might hamper innovation, since the producer is obliged to follow the rules set on how to produce, and little room is left for "thinking out of the box".



Final Remarks

This report aims at providing an overview of food products climate impact. The main source of knowledge is LCA studies of different products, which gives hard numbers and are easy to understand. However, when using LCA some important assumptions are often made that needs to be considered. One of the most important is that the results represent a static picture of reality. The feedback loops from consumption to production are rarely covered, so structural changes in the food system are not accounted for. Moreover, the data quality might differ significantly between studies. So, LCA results should be interpreted bearing this in mind. For a better and more complete picture, scenario studies of different food systems covering more than just climate impact should be performed but such studies presented hitherto are on a high systems level and doesn't inform on details within product groups. Scenario studies needs to be large, and this is very resource demanding and also have inherent limitations, as e.g. how to define scenarios to study which also will be strongly value laden. Conclusively LCA studies presently provide the best basis to understand food systems climate impact, but figures should be interpreted with care when comparing similar products.

As mentioned in the introduction, this report focuses on the climate impact of foods. Food production and consumption contributes largely to other important sustainability aspects which must be taken into account in broader discussions and work on sustainable food systems.

There are obvious knowledge gaps in the quantification of climate impact from products. One is the fact that present data does not include land use and land use change, which is a potentially important parameter for food products. This point is not only about deforestation, which is a "land use change" but also management of soils in general, "land use".

More research is needed, both in order to develop methods to incorporate these issues in LCA, and also to build knowledge about how carbon flows to and from soils are affected by farm practices. A second area of research concerns the emissions of biogenic GHG's, methane and nitrous oxide. This is a complex area since the substances are formed in biological systems; hence vary with e.g. climate, soil type and management.

One aspect that potentially is one of the most powerful in combating food's impact on climate change is the choice of products, i.e. our diets. Since the differences in life cycle GHG emissions are so very large between products fulfilling similar nutritional functions, the scope for improvement is large. In order to efficiently work with "climate smart diets" more knowledge is needed about life cycle impact of single products (not only agricultural data) and connections between diets and how the food chain is affected by changed diets.

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