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Climate gas emissions from food systems – use of LCA analyses

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Motivation[6]

The evolution of conventional agricultural production practices to satisfy the demand for food is argued by many to be one of the major driving forces behind an increased environmental impact and resource consumption in Western households. Current agricultural production contributes heavily to emission of the greenhouse gases CH_4, N_2O and CO_2 – as has been emphasized both by international organisations (IPCC, UNEP, IAASTD, FAO) and by the research community (Tukker et al. 2006; Tukker and Jansen, 2006). Data from Eurostat (2010) show, that the relative importance of agriculture in terms of its contribution to the overall level of greenhouse gas emissions in the EU was 9.2% in 2007 with 462.2 million tonnes of CO_2-equivalents. A study on Europe coordinated by the EU Joint Research Centre (EIPRO study) shows that food and drink is responsible for 20% to 30% of the environmental impact of private consumption in the EU, with meat and dairy products contributing most. Data from the 90-ies in Denmark (Forbrugerstyrelsen 1996) and the Netherlands (Kramer et al. 1994, 1999) show that consumption of food has a 20-35% share of the total energy use in a household.

According to Bye *et al.* (2010) Norway had a total emission of 50.8 mill tonnes CO_2-equivalent in 2009 of which 4.8 mill tons (9%) came from the agricultural sector (48% CH_4, 41% N_2O and 10% CO_2). Greenhouse gas emissions from agricultural practices are primarily in the form of nitrous oxide (N_2O) resulting from the application of fertilisers and manure, tillage of moors and nitrogen emission, or in the form of methane (CH_4) that results, among other things, from livestock emissions, stored animal manure and finally CO_2 from fuel for agricultural machinery. In contrast to most other sources, there are relatively low levels of carbon dioxide emissions resulting from agriculture practices; rather, agricultural land and forests generally sequester (hold) carbon reserves and help to reduce levels of carbon dioxide in the atmosphere. Statistics Norway provides annual numbers for the direct emission of greenhouse gases from each sector in the Norwegian economy (Statistics Norway 2010). However, if we include the emissions arising indirectly from manufacturing of mineral fertilizer, and carbon-losses from arable land management and tillage of moor, the total emission from agriculture rises by some 62% to around 7.8 mill tons CO_2-equivalents (Trømborg et al. 2008). In addition, carbon fixation in grassland (Swensen et al., 2010) is a major sequestration source to consider. Outside the farm gate food processing, transport, storage and shopping structures may also be relevant to consider (Coley *et al*. 2009). It is therefore of questionable merit to look at the impact of agricultural production purely from a sectoral point of view.

Historically most industrialized countries have experienced a shift in energy sources from animals to tractors, and hence from biomass 'fuel' to fossil fuels, increasing overall energy use over time among other through a change in the use of fertilizer from recycling natural fertilizer such as manure and night soil, towards chemical fertilizer, which is industrially mined and processed (Neset and Lohm 2005; Pimentel et al., 2005; Hall et al 1992). The two major substitutes for fossil energy in agricultural production are solar and human energy (Refsgaard et al. 1998). The sun and the fossil fuels differ in their patterns of scarcity. Radian-energy from the sun is practically infinite in total amount (stock), but it is strictly limited in its flow rate. Conversely, energy stored in fossil fuels and minerals is strictly limited in its total amount in a very long perspective (stock), but relatively unlimited in its flow rate-that is, we can use it up at a rate largely of our own choosing (Daly and Cobb, 1989). Solar energy is

[6] This work is carried out through the research project "Socio-economic and environmental impacts of organic farming" running from 2008 to 2011, funded mainly by The Research Council Norway and with additional funding from Oikos, the County Governor Sør-Trøndelag and KSL Matmerk.

indirectly brought into the agricultural production system through crop production, with land and plants acting as solar collectors. The highest quality soils require less human and fossil energy inputs per unit of food produced than the poorer soils. Yet food production can be increased markedly in the short term by investing more energy (Jones, 1989; Hall et al., 1992; Pimentel et al., 1994). It is therefore important to not only focus on the emission of CO_2 but also on the associated land use. Halberg et al. (2005) support this view in their comparison of different types of assessment tools with the purpose of determining the environmental impact of various livestock production systems at farm level including LCA methodology. They mention that most indicator tools present the environmental impacts per hectare and most systems include only the emissions from the farm itself, but that some environmental impacts, e.g. greenhouse gas emission, are of a global nature and therefore the emission per unit produced is as relevant from a global, environmental perspective as the emission per hectare.

Organic farming[7] is an approach to agriculture that emphasises environmental friendly production practices and sustainable resource use and which utilises the market to help support these objectives and compensate for the internalisation of externalities (Lampkin 2003). Relative to conventional farming[8], however, this production system requires more land for the same amount of food output[9]. To compare these production systems with respect to discharges of greenhouse gases it is therefore of more interest to use CO_2–equivalents per unit produced, rather than emissions per hectare, as the relevant indicator. Studies focusing on this comparison have already been conducted for some important food products in various countries (see references in Mondelaers et al., 2009) using life cycle assessments (LCA).

World leaders called for Life cycle assessments (LCA) at the 2002 World Summit for Sustainable Development in Johannesburg, to promote sustainable patterns of production and consumption. LCA is a tool used to assess the environmental impacts of production systems and services, accounting for emissions and resource uses during production, distribution, consumption and disposal of a product (Carlsson-Kanyama et al. 2003, Brentrup et al. 2004, Hertwich 2005). Today LCA is an internationally standardised tool (ISO, 1997, 2006) although questions related to system delimitation, and general principles can be discussed. Since the World Summit in 2002 several LCA analyses have been conducted around the world for a number of typical consumer products and LCAs for food have become more common. Milk, bread, pork and beef are the most comprehensively studied food products (e.g. Møller and Vold, 1995; Weidema et al., 1995; Andersson et al., 1998; Andersson and Ohlsson, 1999; Moilanen, 1999; Cederberg and Mattsson, 2000; Berlin, 2002; Høgaas Eide, 2002; Ziegler et al., 2003; Halberg et al. 2005, Weidema et al 2008, Cederberg et al. 2009. A study by Saunders et al. (2006) conducting a LCA for some key New Zealand food exports to the UK comparing them with the best alternative source for the UK market was found quite controversial as it concluded that the energy costs were much higher for lamb produced in the

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[7] Organic agriculture is distinct from conventional agriculture through alternative agricultural practices, world view and values (Watson et al. 2006) and IFOAM recognizes four basic principles of health, the ecological principle, the principle of fairness and the principle of care being the roots from which organic agriculture grows and develops (IFOAM 2005 cited in Watson et al 2008:2). Inherent within those principles is the idea of farming systems and the links between the production methods and the health of the consumer. For an overview of organic rules and certification in EU, European countries and the US see http://organicrules.org/custom/completestandard.php.

[8] As in Nemecek et al. (2011) we define conventional farming in this study as a mode of production not respecting the organic farming rules (see link in footnote 1). The agricultural system's main goal is to achieve high yields and a high economic output.

[9] Meta-analysis' by Mondelaers et al. (2009) and by Badgley et al. (2007) report an average organic/conventional yield ratio of respectively 83 and 91 per cent for developed countries for all crops.

UK than for NZ lamb. This was due to several causes like cooling facilities, type of energy used, type of transport medium etc. (Kemp et al. 2010). The lesson learned from this example is that our analyses have to be conducted for the whole system, from 'cradle to grave'.

It is therefore not obvious how the emission of climate gasses are influenced by a change in production intensity, as reduced yields might counterbalance any energy savings from reducing external inputs. Any restrictions imposed in a part of a farming system might be substituted for in other parts of the system by the farmer. Therefore, it is an interesting and complex question whether less intensive farming systems have lower climate gas emissions than more intensive food systems.

Purpose

This article aims to present a systematic overview of production of four different and common agricultural products and their emissions to air of CO_2 and associated land use. This includes analysis of the environmental consequences with respect to CO_2 emission and land use of food production and for different food production systems to be able to answer questions like

a. What are the large emission processes?

b. How does the emission vary with product and with production system?

c. What is the trade-off with land?

d. How does the data from Norway compare to other studies?

e. What are the variations and the uncertainties?

f. What is the potential for reduction of CO2-emissions?

Methodology and data

Models for Norwegian farm based on data from Farm Account Data Analyses (FADN) producing milk, meat and grain under different production systems were analysed according to their emission of CO_2-equivalents from CO_2, CH_4 and N_2O. The assessment was carried out within the framework of life cycle assessment (LCA) to include both direct farm emissions as well as upstream indirect effects from production of inputs to farm activities. The product life-cycle covers all processes from extraction of raw material, via production, use, and final treatment or reuse (Wenzel et al. 1997, Guinée 2001, Baumann and Tillman 2004, ISO 2006). The reader is referred to these references for a more general introduction to LCA methodology.

In addition to the emission of CO_2, CH_4 and N_2O also the use of land is analysed as this is a major substitute for fossil energy and other resources in agricultural production. Further higher quality soils require less human and fossil energy inputs per unit of food produced than poorer soils. It is therefore important to not only focus on the emission of CO_2 but also on the associated land use and the yield potential.

Data sources

The objective of this work is to represent average Norwegian farm production rather than norm-based production with more regulated and specific characteristics. Further using data from whole farms instead of disaggregated data from trials etc. is important because simple relations between individual input factors, processes on the farm, climate emission and land use cannot be expected as input factors and processes may substitute each other (Refsgaard et al. 1998). By using data from whole farms we are able to track the substitution and the 'lacking' resource use due to integrated production processes.

Agricultural production in Norway varies considerably with respect to farm size, composition of production output, geographical and climatic conditions, and farming practices. Farms from the account statistics are grouped according to main production output(s) into model farms representing different production systems, different farm sizes and different regions in Norway. The aggregation into model farms is carried out on an annual basis by the Norwegian Agricultural Economics Research Institute, and includes 27 different farm types of which 15 are on a national level and the remaining are subsets representing different regions. The models are based on account statistics from annual surveys of more than 800 farms in Norway (Driftsgranskninger i jord- og skogbruk). In our analyses the following model farms have been used for the years 2005-2007, see Table 1.

Table 1: Model farms used for analyses of CO_2-emissions

Acro-nym	Name	Production system	Size	No of farms as source	Data covering
Ref1	Referansebruk no 1	Milk and beef meat	20 annual cows	341	Country
Ref2	Referansebruk no 2	Grain	333 daa	88	Country
Ref5	Referansebruk no 5	Pork and grain	46 sows, 357 daa grain	38	Country
Ref7	Referansebruk no 7	Potatoes and grain	103 daa potatoes, 335 daa grain	13	Country
Ref8	Referansebruk no 8	Beef cattle / suckler cows	25 suckler cows	33	Country
Ref10	Referansebruk no 10	Chicken and plant products	80383 chicken slaughtered	15	Country
Ref11	Referansebruk no 11	Organic milk and beef	20 annual cows	23	Country
Ref14	Referansebruk no 14	Milk (the 40 largest)	40 annual cows	40	Country
Org W	Modelled farm by Agricultural Advisory Service (SørØst)	6 years crop rotation with green manure	Green manure, wheat, oat w/under culture, oat/peas, rye w/grass, green manure	Experiences from extension service	Eastern Norway

Source: Adapted from "Referansebruksberegninger"
Model farms covered in this study are listed in Table 1. For each farm type, the following inventory approach is used.

Physical units for intermediate farm inputs and production:
Physical units for intermediate farm inputs and production are calculated from monetary value for reference farms, based on unit price (Budsjettnemnda for jordbruket 2008b, Budsjett-nemnda for jordbruket 2009b). Various other costs and income are also available but were not used in this study. Both unit prices, and the volumes of intermediate inputs are averages for the period 2005-2007

Data for model farms and prices are gathered and averaged for the last three years' data sets (2005-2007) to provide more robust inventory data and account for price fluctuations for both inputs and outputs, fluctuations in production yield due to weather and climatic conditions, changes in production output composition and crop rotation.

Construction of the LCA model is significantly simplified by the standard format used for reference farms. Both intermediates and products are listed and registered in a strict format, enabling consistent and easy implementation and update of model values.

Table 2 shows an example of registered inputs to, and Table 3 shows outputs from, farm production. In this case the example is dairy farm. For model farms with livestock, feed concentrates is the largest purchase. These input categories represent all types of chemical fertilizers, feed concentrate composition and so on. Assumptions about composition and manufacturing of the various inputs to production are provided in Appendix A.

In the case of a specialized cereal farm the main outputs being barley, wheat and oat all together making up almost 90 % of total output in monetary units. The largest purchases are fertilizers, fuel and seed grain. The remaining posts are made up of products that are not descriptive of cereal production, but reflect that farms often also have a small production of other agricultural products.

The statistical accounts report only monetary flows entering and exiting the farm gate, i.e. internal production and use that are not represented by a purchase or a sale cannot be separated out from the data sets. This implies that for example internal production and use of fodder is covered indirectly by its share of the purchases, but the share cannot be distinguished.

Organic cereal production

Organic cereal production is not covered by any of the reference farms, and must therefore be modelled separately. An organic grain/cereal production without animals was defined based on information from the Agricultural Advisory Service (LF SørØst). This Agricultural Advisory Service is located at Østlandet, the area receiving 68% of the subsidies for organically grown grain in 2008 (Agricultural Authority 2009, NILF 2009). This is the area most common with a crop rotation without animal husbandry. The data from the Agricultural Advisory Service are based on knowledge from farm production in their area.

Table 2: Registered inputs to farm production. An example of a dairy farm

Referansebru	Kode	Input	Fysisk (kg)	Justert, fysisk (kg)	Enhetspris	Verdi (NOK)	Andel (%)	Justert, andel (%)	Justert, sum (NOK)	
1	1240	Jordbruksareal i alt	360,93							
11	3000	Såkorn				7048				
		Bygg	1166,90	1670,05	3,96	4 621	1,69 %	2,41 %	6613,38	
		Havre	647,22	926,29	3,75	2 427	0,89 %	1,27 %	3473,59	
11	3010	Settepoteter	40,77	58,35	3,9	159	0,06 %	0,08 %	227,56	
11	3020	Såvarer og planter				9 398	3,43 %			
11	3030	Handelsgjødsel	998,57	1429,14	2,1	2 097	0,76 %	1,09 %	3001,19	
11	3040	Kalk	3368,00	4820,22	0,5	1 684	0,61 %	0,88 %	2410,11	
11	3050	Plantevernmidler				26	0,01 %			
11	3060	Konserveringsmidler				6 257	2,28 %			
11	3070	Kraftfôr	44405,28	63552,03	2,65	117 674	42,92 %	61,43 %	168412,88	
11	3080	Annet innkjøpt fôr	58023,08	83041,57	0,39	22 629	8,25 %	11,81 %	32386,21	Antar grovfôr.
11	3090	Diverse til husdyrholdet				27 101	9,89 %			
11	3100	Innkjøp av dyr				8 718	3,18 %			
11	3110	Andre forbruksartikler				31 092	11,34 %			
11	3370	Drivstoff	3759,72	5380,84	0,17	22 116	8,07 %	11,55 %	31652,02	
11	3410	Elektrisk kraft	21489,83	30755,86	0,84	18 141	6,62 %	9,47 %	25963,07	
		Total, inkl. ukjent				**274 140**	100,00 %		**274140,00**	
		Total, eks. ukjent				**191 548**		100,00 %		
		Ukjent				**82 592**	30,13 %		82592,00	

	Mellomregninger		
Kode 3000	Type	Mengde (kg)	Andel
	Bygg	1557,90	0,66
	Havre	818,27	0,34
	Total	2376,17	

Source: Adapted from Budsjettnemda for jordbruket 2007; 2008a and 2009a

Table 3: Registered outputs from farm production. An example of dairy production.

Basert på Driftsgranskningene til NILF (snitt 2005-2007)
Referansebruk: **11**
Antall bruk (snitt) 24
Økologisk melk og storféslakt, 19 årskyr

Prisene for output er snitt for årene 2005-2007, og hentet direkte fra referansebruksberegningene så langt som mulig. Manglende priser for output, og alle prisene for input, er hentet fra totalkalkylene til NILF (med unntak av elektristet fra SSB, Statistikkbanken). Prisene er snitt for årene 2005-2007.

Referansebru	Kode	Output	Fysisk (kg)	Enhetspris	Verdi (NOK)	Andel (%)	
11	2100	Bygg	1557,90	2,27	3 532	0,60 %	
11	2110	Havre	818,27	1,65	1 353	0,23 %	
11	2120	Hvete	-36,33	-8,46	307	0,05 %	
11	2130	Annet korn			-46	-0,01 %	
11	2140	Oljefrø			366	0,06 %	
11	2150	Poteter	140,60	6,36	894	0,15 %	
11	2160	Grovfôr	22578,63	0,39	8 806	1,49 %	
11	2180	Andre planteprodukter			1 837	0,31 %	
11	2300	Storfe, melk	104148,47	4,20	437 905	74,21 %	
11	2310	Storfe, livdyr			30 618	5,19 %	
11	2320	Kuslakt	1849,87	31,23	57 775	9,79 %	
11	2330	Annet storfeslakt	1231,30	35,11	43 229	7,33 %	
		Samlet storféslakt	3081,17		101 004	17,12 %	Kode 2320 + Kode 2330
11	2350	Geit, livdyr og slakt			159	0,03 %	
11	2360	Slaktegris	156,53	18,90	2 958	0,50 %	
11	2390	Sau, livdyr og slakt			82	0,01 %	
11	2420	Sau, ull	0,27	37,50	10	0,00 %	
11	2440	Andre inntekter husdyrhold			276	0,05 %	
		Sum annet			37 460	6,35 %	
		Total, inkl. ukjent			**590 060**	100,00 %	
		Total, eks. ukjent			**552 599**		

Source: Adapted from Budsjettnemda for jordbruket 2007; 2008a and 2009a

Direct and indirect emissions from fertilization and husbandry

Direct and indirect emissions from fertilization and husbandry are modelled using an adaptation of the national greenhouse gas accounts for agriculture, with Tier 2 resolution for most factors (Sandvik, 2009). Emissions are normalized per animal, per mass of fertilizer N and P applied, and per volume of manure; see documentation elsewhere (Pettersen 2010) Fertiliser use and stock of animals are reported for each reference farms, and these are used directly in the inventory model without adjustment for organic or conventional feeds.

Manufacturing of input factors

Manufacturing of input factors is modelled using the Ecoinvent database, with some modifications for the most important inputs, most notably fertilizer production and feed concentrate production which are modified according to Norwegian production and use (see Appendix A).

Allocation for farm operations

Allocation for farm operations is based purely on price of production. Economic allocation is used for distributing the inputs between the different outputs, i.e. if a farm output represents 25 % of total income from sales (subsidies excluded), this output is assigned 25 % of each input to the farm and the corresponding impacts from production of these inputs. This implies that some outputs are also assigned a share of inputs that are not used in their production.

Physical inputs to farm production for a model farm are presented in Table 2. Some inputs are marked to indicate that they are not modelled directly. This concerns input categories containing miscellaneous products with unknown composition, and mostly with a small share of the total value of inputs. A notable exception is the use of pesticides which makes up a considerable share of the value of inputs for model farms with cereal production. Rather than excluding these input categories and systematically underestimate emissions from production of inputs, they are accounted for by distributing their value on the other input categories according to their share of total input. Miscellaneous input categories are therefore included in a simplified but consistent manner.

Issues in the inventory approach

- We assume that organic and conventional animals have the same direct and indirect emissions, i.e., no adjustment for different feeding practices or treatment of manure. However, organic fed cows eat more grass, thereby should have more enteric emissions
- The reference farm data do not identify whether manure is transferred from conventional to organic farming. This may be interpreted as allocating downstream emissions always to the origin of the manure, i.e., to the owner of animals. However, manure application is a major emission source for organic farming and should be included as an intermediate in their production.
- The farm level scope used makes it difficult to make product-by-product comparison for typical multi-output products, as we cannot identify use of intermediates to specific products.
- Manure management is an important aspect of greenhouse gas emission from husbandry. Our inventory model relies on national averages for the direct and indirect emission from manure storage and application, and should be made more detailed to allow estimation of the effect of using different management practices.

Table 4: Average yield levels for dairy production and plant production systems

		Grass domestic	**Grain domestic**	**Feedstuff import**	**Milk**
		Feed Units per ha	*kg per ha*	*kg per ha*	*kg per cow*
Dairy	Conventional	3 500			6 064
	Organic	3 000			5 234
Grain	Conventional		4 720	5 000	
	Organic		1 965	5 000	

Sources: Budsjettnemda for jordbruket 2007, 2008a, 2009aMcIntyre et al (2009), IIASTD-report, Forsøksringen SørØst

Land use

Land use

Land use is modelled in a simplistic approach, only including the direct land use in farming but including land both from imported as well as national produced inputs. These calculations are carried out outside the life cycle analyses operations.

Average yield data from the years 2005-2007 for reference farms are used for calculating the land use for production of 1 kg of each of the products grain and potatoes as well as for the land use for fodder used as input in the dairy and beef production. For the imported feedstuff FAO-data from the IIASTD-report with 5,000 kg of wheat per hectare as a rough estimate for ten NAE countries. For the organically grown grain the yield levels are based on information from the Agricultural Advisory Service (LF SørØst) as they are located in the area most of the organically grown grain is produced (68% of the area in 2008).

The yield levels (for both plant production and for dairy production) under different conditions for the different products are shown in Table 4.

Results

The emission of CO_2-equivalents and the use of land for food production until farm gate

In Figure 1 the emissions to air of CO_2-equivalents is shown both per kg food and per mcal. The CO_2-emission per kg food is much higher for the animal products than for the plant products. However, when the energy content of food is considered the differences are reduced heavily especially between meat and milk. The emission from meat is from 6 to 9 CO_2-eq per mcal, from milk it is 3.58 – 4.09 kg CO_2-eq per mcal milk, while production of wheat only contributes with from 0.14 - 0.24 kg CO_2-eq per mcal. For all products the average numbers for conventionally products are from 30% to 70% higher than for the organically products with the lowest difference for beef.

For land use we see a different picture. Organically produced food has in average 10% to 70% higher land use of land than conventional produced food with the lowest difference for beef. Within each type of production system the land use for animal products are higher than for plant products with around 16-17 m^2 per mcal meat compared to around 1 m^2 per mcal wheat.

Comparing organic production with conventional production shows that the CO_2-emission in general is lower for organic products than for conventional products, and that land use is higher. The relative difference between the production systems is about the same but ‘opposite’ for each of the products.

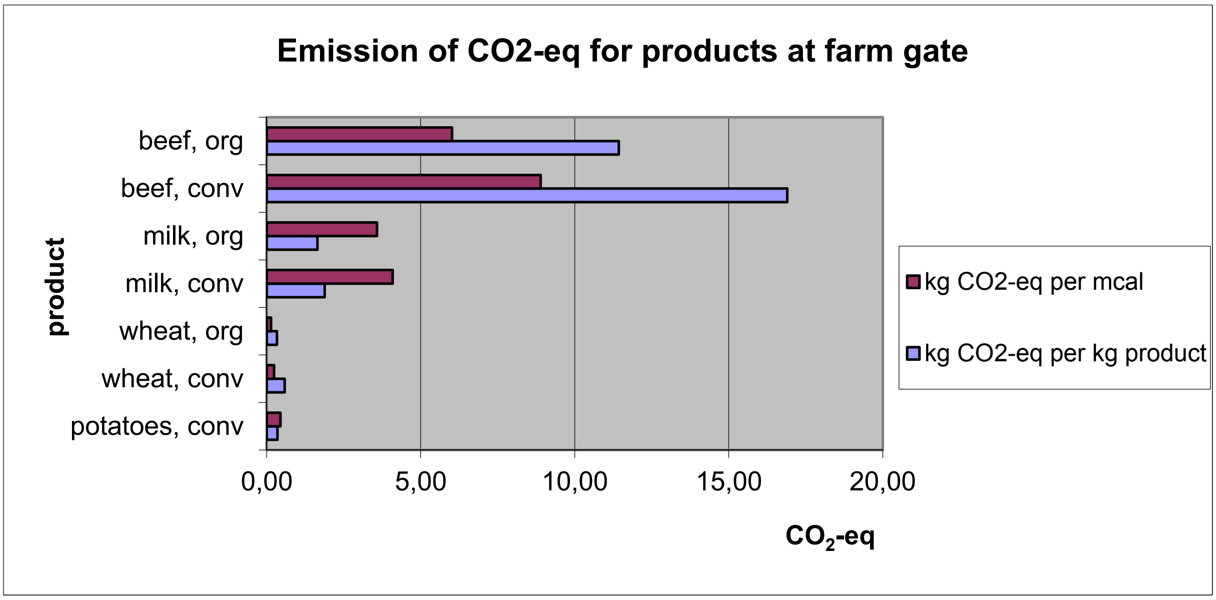

Figure 1: Emission of CO_2-equivalents for different food products in Norway. Average numbers based on Referansebruk[10]

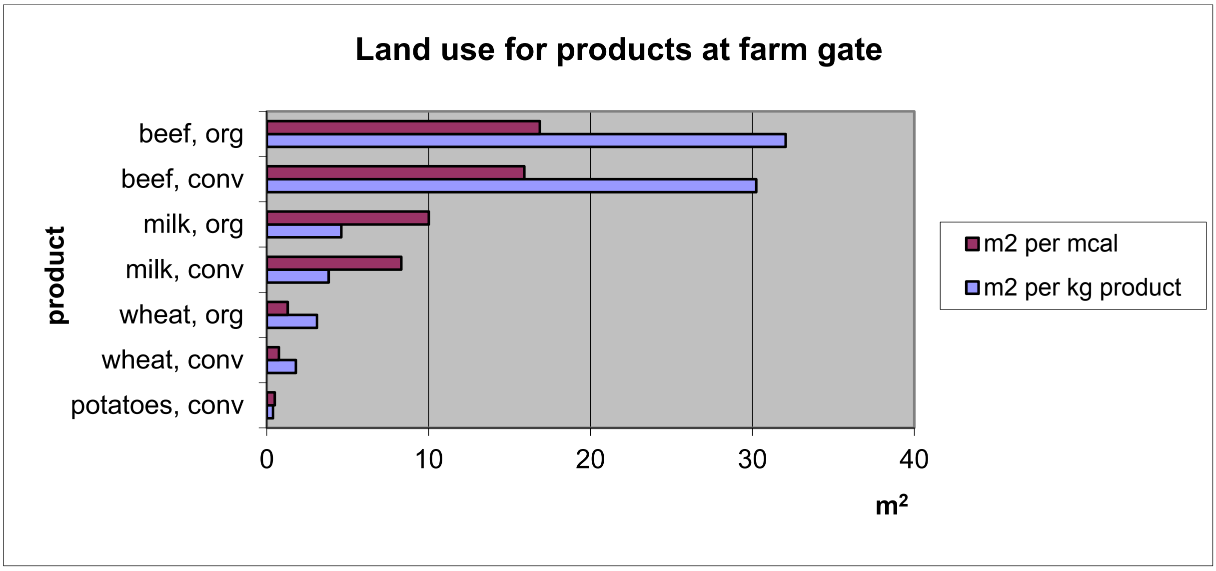

Figure 2: Land use for different food products in Norway[11]

[10] Average numbers for conventionally produced food is composed as a weighted average of the different Referansebruk. For beef MF1 counts 76% (15.1 CO_2-eq of which 8.1 is direct emission at farm gate), MF8 counts 9% (34,1 CO_2-eq of which 20.1 from direct at farm gate) and MF14 weighs 15% (15.06 kg CO_2-eq at farmgate).

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Composition of CO_2-eq emissions and variation between different production systems

There is a variation in the CO_2-emission by producing each of the analysed products depending on type of production system. In Figure 3, 4 and 5 the contribution of the different sources of inputs for manufacturing and production for different production systems can be seen.

In Figure 3 we see results from wheat production at six different 'Referansebruk' with a variation from 0.34 to 0.72 kg CO_2-equivalents per kg wheat at farm gate. The mineral fertilizer including both manufacturing and fertilizing contribute with the major part of the CO_2-emission from the conventional production systems without animals (Ref7Pt, Ref7W, Ref2W) while feed concentrates is a large source for the production systems producing plants in a production system with animals. However the feed concentrates is indirectly also having mineral fertilizer as their main source for CO_2-emission. The organic wheat production using green manure in two out of six years in the crop rotation has its main source for CO_2-emission from green manure.

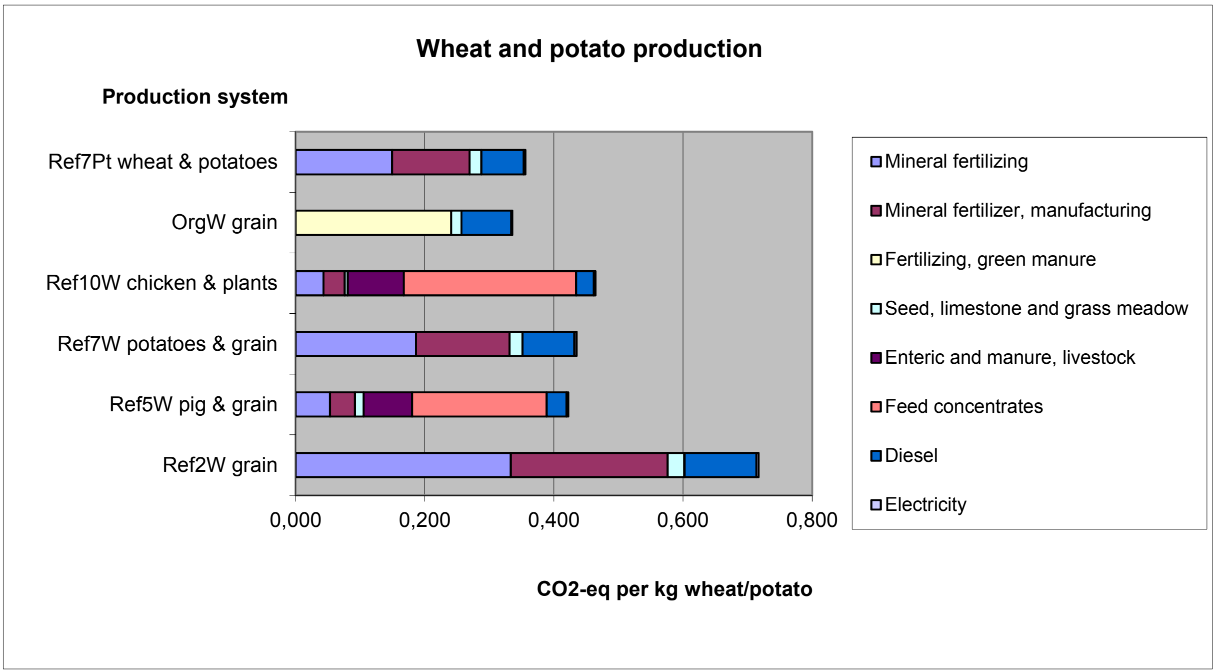

Figure 3: The sources for CO_2-eq emissions from production of wheat and potatoes in different production systems

In Figure 4 we see that the largest main contributor to CO_2-emission from milk is the direct emission from husbandry production, i.e. the CH_4 and N_2O from digestion and manure contributing with 54% of the total emission at farm gate from conventional production and 71% from organic production. The difference between the three analysed production systems is mainly the mineral fertilizer contributing with climate emission from processing of nitrogen through CO_2 and N_2O / NH_3 and from fertilizing on the farm through N_2O for the two conventional production systems.

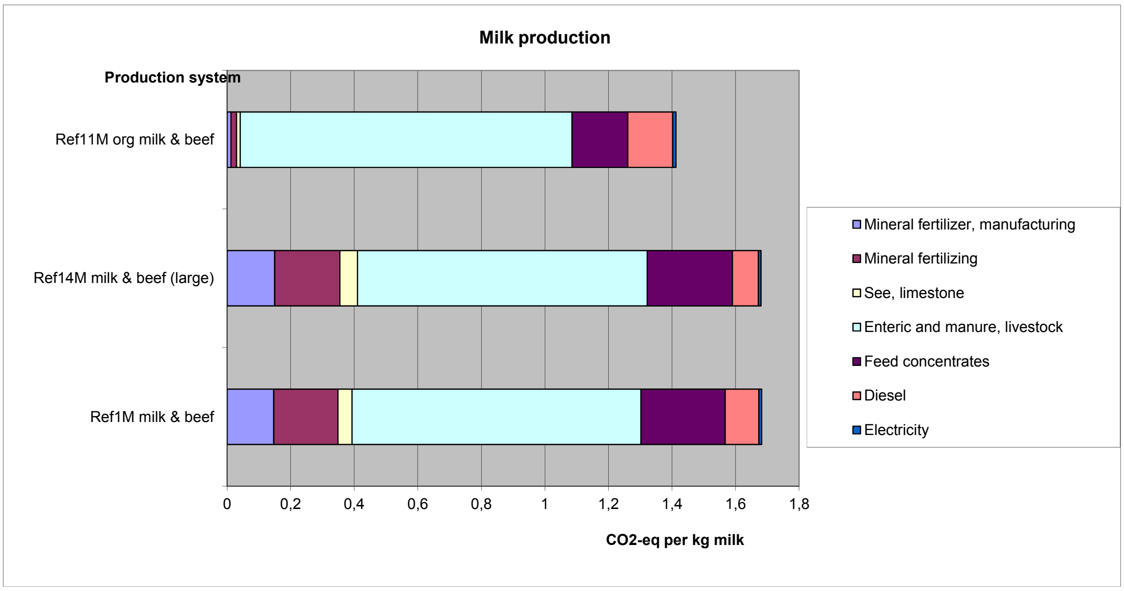

Figure 4: The sources for CO_2-eq emissions from production of milk in different production systems

Meat production varies heavily depending on whether it is beef, pork or poultry. In figure 5 we see that all light meat (chicken and pork) have much lower emission of CO_2-equivalents, 2.73 - 4.5 kg CO_2-eq per kg product, than beef production. The CO_2-emission from beef meat produced in combination with milk (Ref1B, Ref11B and Ref14B) emits less than 50%, 11-15 kg CO_2-eq per kg beef, is only half the CO_2-emission when produced from suckler cows, 34 kg CO_2-eq per kg beef meat.

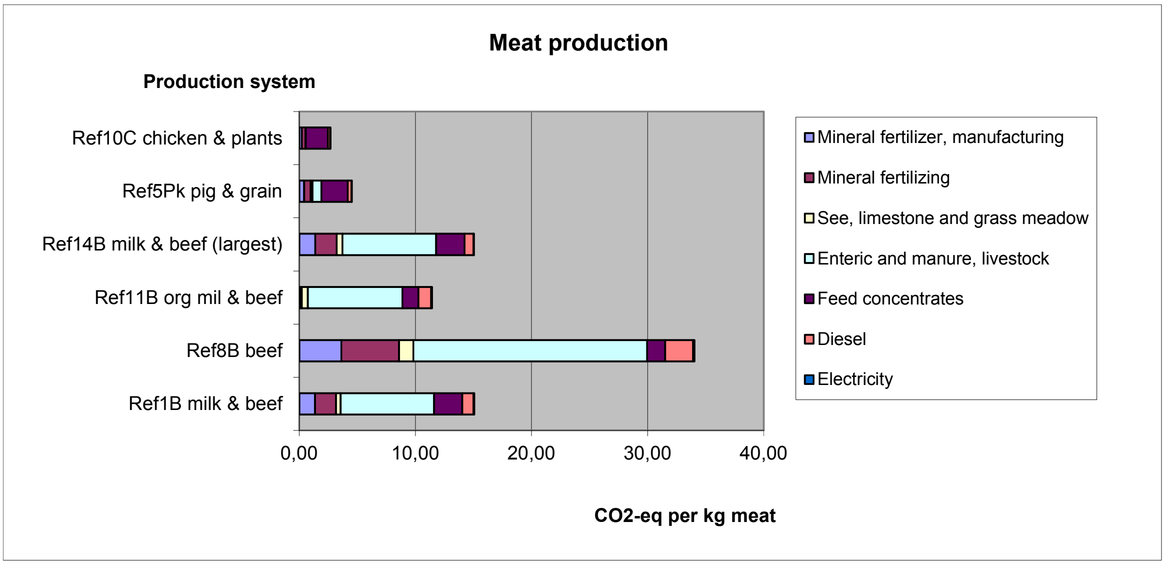

Figure 5: The sources for CO2-eq emissions from production of meat in different production systems

Comparison of our results with results from across the world

Various studies have compared the environmental impacts of conventional, integrated and organic farming. The following short review concentrates mainly on LCA studies. Most of the publications cited came to the conclusion that the environmental impacts per cultivated area are reduced in organic farming systems as compared to conventional agriculture. In an evaluation per product unit, the authors found lower, similar or higher impacts of organic farming, depending on the production system, site effects and differences in management intensity. The following overview concentrates on the evaluation per kg of product.

Many studies report a lower energy demand per product unit, e.g. Refsgaard et al. (1998) and Cederberg and Mattsson (2000) for organic milk production, but the energy demand can also be similar (Bailey et al., 2003) or higher (Kramer et al., 2000) than for conventional farming. A conversion to organic farming would increase energy efficiency of Danish agriculture (Dalgaard et al., 2001). Lötjönen (2003) showed that machinery operations can use up to twice as much energy on organic than on conventional farms – while the energy efficiency analyzing farm production systems in Denmark as a total was better in organic farming than in conventional farming for both grass, grain and milk production in Refsgaard et al. (1998).

For the global warming potential, the results are less clear. Organic Irish suckler-beef production had lower emissions of greenhouse gases than conventional production per area and per product unit (Casey and Holden, 2006). Also organic apples had a lower global warming potential (Milà i Canals et al., 2001), while organic baby food (Mattsson, 1999) or organic milk (De Boer, 2003) and various other products (Williams et al., 2006) showed higher emissions per product unit.

Many studies investigated only the average differences between the systems. However, there is also a considerable variation within a given farming system (Mouron et al., 2006; Rossier and Gaillard, 2001; van der Werf et al., 2009). The cited studies compare organic, integrated or conventional farming in a series of case studies. Depending on the actual management intensity, farming context, climate and soil conditions, crops, etc. they come to partly contradicting conclusions. None of these studies make a systematic evaluation of a series of farming systems or crops that would allow drawing conclusions for Swiss organic and integrated farming systems and furthermore most of these studies focused on single crops and did not consider the impact categories biodiversity and soil quality that are of particular relevance for organic farming.

As mentioned above, various studies have carried out ‘cradle to grave’ comparisons of the environmental impacts of conventional and organic farming. Meisterling et al. (2009) investigated wheat flour production finding the organic method to be superior, while Nemecek et al. (2011, Switzerland) found that the two production systems also could be similar in that respect.

As Hospido et al. (2010) argue, the environmental impact from animal and vegetable products often differs by a factor of 10. Our results also show large differences in impact between animal and vegetable products, but the difference is much larger, around 20 between grain and milk and around 40 between grain and beef, when comparing nutrient value instead of comparing kilo. Swedish studies carried out by Cederberg et al. (2009) report 20 kg CO_2-eq per kg carcass weight at retailer, compared to 17.7 kg CO_2-eq per consumed kg meat for Norwegian conventional production. Nguyn et al. (2009) report that GHG-emissions from primary production of beef in Europe are in the range of 15-27 kg CO_2-eq kg per kg carcass weight at farm-gate, with beef produced as by-products from milk production in the lower end of the range and beef produced in “cow-calf systems” in the upper end. From Nguyen et al. (2010) studying four beef production systems – three from intensively reared dairy calves and one from suckler herds we find the following results. Analysis of the contributions from production of 1 kg beef meat (slaughter weight) to global warming, acidification, eutrophication, land use and non-renewable energy use were lower for beef from dairy calves than from suckler herds (16.0–19.9 versus 27.3 kg CO_2-eq, 101–173 versus 210 g SO_2-eq, 622–1140 versus 1651 g NO_3-eq, 16.5–22.7 versus 42.9 m^2 per year, and 41.3–48.2 versus 59.2 MJ, respectively).

Cederberg et al. (2009) calculated 1.08 CO_2-eq per kg milk at farm gate in 2005 compared to 1.65-1.88 CO_2-eq per kg milk from our studies. When dividing the emissions between milk and beef, Cederberg et al. used an allocation factor of 85 % to milk and 15 % to meat (culled cows and surplus calves further to be raised in beef production), In our calculations the economic contribution being in average 67% to milk and 25% to beef in conventional and 74% to milk and 17% to beef in organic combined dairy production. Weidema et al. (2008) have calculated the CO_2-eq emission from Danish milk production to be 2.4 CO_2-eq per kg and 28.7 CO_2-eq for dark meat.

Floren et al. (2005) have calculated the emissions from Swedish studies from 2000 and for about 20 case study farms to be about 0.98 kg CO_2-eq per kg conventional milk and 0.95 CO_2-eq per kg organic milk.

Analyses of the variations and of the uncertain data

There is a great deal of uncertainty related to calculations of climate gas emissions which is due to different aspects including among others:

- Uncertainty related to the coefficients used – among other related to the use of estimates for indirect and direct emission from husbandry and fertilization being major emitters.
- The generalisation of coefficients like CH_4 emission from the dairy production related to type of feeding regime
- The system boundaries – which are not uniquely defined in the referred studies.
- The system boundaries – which are complex to define as they involved decisions about alternative possibilities for use of inputs and outputs.
- Variation due to our data material due to weather and wind, farm management etc.
- The allocation issue in combined production

Direct emission from milk and meat from ruminants

In calculating the direct emission from milk and beef meat production we have used constant coefficients for CH_4-losses from enteric fermentation[12] and from animal manure in stable and storage as well as for N_2O from animal manure. The emission of CH_4 from the management of manure is dependent of type of storage, spreading and treatment. Also the loss of N_2O (indirectly through NH_2) and directly from manure management is dependent of type of storage and spreading. However these losses has a much lower contribution to the direct emission than methane and will not be further investigated here.

[12] 143 kg CH_4-loss/dairy cow/year (Volden and Nes, Sundstøl and Mroz 1988, IPCC 1997, Salmo (ed) 2009, Pettersen 2010)

Trømborg et al. (2006) have made estimations analysing the variations in enteric CH_4-emission related to production intensity[13]. Using the estimates by Trømborg et al (2006) a decrease in yield on 1 000 kg per cow would imply a 10% increase in CH_4-emission per kg milk[14]. The result is a decrease in difference between milk produced organically and milk produced conventionally with about 100 000 tons CO_2-equivalents for the total production of 1 500 mill l milk[15].

Mineral fertilizer

The other large contributor to CO_2-emission from conventional production of all farm products and contributing to a difference to organic production is manufacturing and application of mineral fertilizer. It contributes 21% of the total emission for milk and 69% of the total emission for wheat. In our calculations the coefficients for CO_2-emission from fertilizer processing are based on the current technology from Yara[16], being about the most energy efficient technology available. This implies that by using other technologies with less efficiency the CO_2-emission will increase. The fertilizing coefficients are very uncertain and therefore rough estimates[17].

Carbon sequestration in soil

Changes in the soil carbon pool have not been accounted for. Riley (pers. comm. in Trømborg et al. 2006) has calculated the loss from arable land in the Eastern part of Norway to about 2 000 kg CO_2 per ha. The total loss from arable crops can then be estimated to – for all cropland (domestic and imported) about 1.73 mill tonnes CO_2-eq for conventional production and 1,69 mill tonnes CO_2-eq for organic production. Danish experiences (Petersen et al. 2006) are that 'livestock-crop rotations', including the area for feed-cereals, in total will have a zero net impact on soil carbon pools (grass based and manure rich crop rotations increase C-pool, whereas cereal production decreases).

DISCUSSION

In this paper, we have looked at emissions of CO_2-equivalents arising from the three main sources in agriculture, CH_4, N_2O and CO_2. All three sources contribute to emission from agriculture and production of food but the contribution from agriculture differ according to production system like organic versus conventional combined dairy and beef meat production and between beef meat production in combination with milk production versus in suckler cow production. There are also large differences between production of food energy from cereals compared to food energy from beef meat compared to food energy from milk.

Life Cycle Assessments (LCA) has been used as the methodology to analyse the differences between production systems and between different types of food for emission of CO_2-equivalents. In this paper the LCA include the emissions arising from manufacturing of inputs like mineral fertilizer as well as the production on the farm until farm gate. In addition we

[13] 145,8 kg CH_4-loss per 6000 kg milk per year (Trømborg et al. 2006)

[14] Assuming a linear relationship between the yield and CH_4-emission and with a conventional dairy production set to 6 000 kg milk[14] and the organic production to around 5 200 kg milk per cow per year.

[15] The total consumption of milk in Norway is 1 500 million litres (Budsjettnemda for jordbruket 2009b)

[16] Of about 1,5 kg CO_2-eq (0.005 kg N_2O) per kg N together with about 3 kg CO_2 from use of gas in the hydrogen production in total 4,5 kg CO_2-eq per kg N (Yara)

[17] We use 0.0269 kg N_2O per kg mineral fertilizer N which includes the indirect contribution through evaporation to ammoniac and nitrogen run-off and direct contribution from N_2O-N (Pettersen 2010). Trømborg et al. use 0.019 kg N_2O per kg N.

have analysed the land use for the same production systems and food varieties as this resource is the main substitute through the use of the sun as an alternative energy source and land an alternative to among other mineral fertilizer and pesticides. The analyses of land use include both the land used to produce inputs outside Norway as well as for domestically produced inputs.

Such analyses are useful to identify key areas in food production systems to find more sustainable management strategies to improve environmental performance and lower the emissions of CO_2-equivalents.

Statistics Norway provides knowledge about emissions from a sectoral view point[18]. This gives not an acceptable starting point for analysing possibilities for lowering CO_2-emissions. This is due to the fact that a good part of the emission related to production of food arises in other sectors. Comparing different food production systems must therefore include the emissions arising from the inputs (and outputs) from other sectors. The LCA methodology was therefore seen as appropriate as it has a product focus – tracing back from e.g. production of a kg of milk the emissions of CO_2 as well as the land use under different production systems and methods.

We used data from NILFs FADN-farms (Driftsgranskningsbruk) modelled by Budsjettnemda for jordbruket to model farms (Referansebruk) representing different production systems. whole farms we are able to track the substitution and the 'lacking' resource use due to integrated production processes.

The results show that for each of the products analysed wheat, milk and beef meat there are generally lower emissions from the organic production system than from the conventional system if we look at overall average numbers for different types of model farms. The average numbers for conventionally products are from 30% to 70% higher than for the organically products with the lowest difference for beef. There is however variation in the CO_2-emission for each of the analysed products depending on type of production system. The CO_2-emission from beef meat produced in combination with milk is only half the CO_2-emission when produced from suckler cows where the emission is around 34 kg CO_2-eq per kg beef meat.

In general the CO_2-emission per kg food is much higher for the animal products than for the plant products, although the differences are reduced especially between meat and milk when the energy content of food is considered. The emission from meat is from 6 to 9 CO_2-eq per kg kcal, from milk is around 4 CO_2-eq per kg kcal, while production of wheat only contributes with from around 0.2 kg CO_2-eq per kg kcal.

For land use, organically produced food has on average 10% to 70% higher use of land than conventional produced food with the lowest difference for beef. Within each type of production system the land use for animal products are higher than for plant products with around 16-17 m^2 per kg kcal meat compared to around 1 m^2 per kg kcal wheat.

The results show that there are relatively large emissions from mineral fertilizer which are not accounted for in the official estimates from the agricultural sectors. This implies among other that systems not using mineral fertilizer like organic farming systems show lower emissions

[18] Norway: 50.8 mill tonnes CO_2-eq in 2009 (Bye et al. 2009). Of these 9% (2008: 2.1 mill tonnes CH_4 and 2.2 mill tonnes N_2O) from agriculture (48% CH_4, 41% N_2O og 10% CO_2). Methane (14 % from anaerobic storage of animal manure, 86% from ruminants).

measured per kg product. This was also considered by Trømborg et al. (2006), who corrected the official numbers for emission of climate gasses as calculated by Statistics Norway such that mineral fertilizer and carbon sequestration from moors and cultivated land were included. This implied that the total emission from agriculture up to the farm gate was calculated to be roughly 7 799 000 tonnes CO_2-eq in 2006.

The analyses carried out in this project and reported here shows that when comparing the emissions of CO_2-equivalents for producing food one has to consider the sectors providing inputs to agriculture as these contribute with considerable emissions. Further it is important to consider the whole farm system when comparing production of food – and in this respect the model farms through FADN-data from NILF/Budsjettnemda for jordbruket have shown to be very useful. The use of land is of high importance to consider in comparison of the emission from different systems being the most important substitute for fossil energy. Our data material and the results provide therefore basis for analyses of different scenarios . E.g. Norway has excessive area for grassland and scenarios analysing substitution of imported protein with grass in changed feeding and management strategies for producing milk and meat may have political interest. The final choice for consumption of food can have very large impacts on the emissions of CO_2-equivalents – as the differences between emissions from plant versus different animal products show. In NILF-discussion paper 2011-3 these issues are further elaborated using the results from this study.

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Appendix A

Modeling of inputs to production

This section describes the key assumptions on how various inputs from the model farm statistics are modeled in the inventory.

Seed grain

Input of seed grain to model farms is reported as one group without a split between grain types. Input of seed grain is distributed on the three cereal types that are reported; barley, wheat and oat, and a category termed other grain for the remaining fractions. Distribution is performed according to production volumes. Production volumes are calculated from reported income from output of the individual cereal types in the model farms and converted to physical units through price information.

Fertilizer production and use

The major share of fertilizer use in Norwegian agriculture is produced domestically by Yara [REF. Svoldal 2005]. Personal communication confirms that their main production facility in Porsgrunn, Norway, is producing fertilizer in accordance with the BAT-document issued by the European Fertilizer Manufacturer's Association (EFMA) for production of NPK fertilizers by the nitrophosphate route [REF. BAT-document].

Ecoinvent processes for production of N, P and K are modified to represent specific mix for the fossil part of the energy use for the plant in Porsgrunn, averaged for the years 2005-2007 [REF. Norske utslipp]. Fossil energy use is reported as 70% natural gas, 20 % light fuel oil and 10 % heavy fuel oil. The composition changes however considerably between years. The modification to specific fossil fuel use has a small effect (<5%) relative to the generic database production process.

The use of fertilizers varies according to farm type and products, and access to manure. Cereal production requires a different mix of nutrients than for example potatoes or cattle products. NPK fertilizer mixes are used for all fertilizer use, but with varying composition of the three elements according to farm type and production.

All fertilizer use on cereal farms is modeled with NPK 21-4-10, with numbers indicating the shares of the N, P and K. Model farms producing mainly cattle products are modeled using a mix of NPK 18-3-15, NPK 21-4-10 and NPK 22-2-12. This composition is based on annual statistics about the trade within the agricultural sector [Budsjettnemda for jordbruket 2008b, Budsjettnemda for jordbruket 2009b], and is 21%, 57% and 22 %, respectively for the three fertilizer mixes. Fertilizer use of potato production is modeled with NPK 11-5-17. Model farms producing a mix of products with different fertilizer profiles are modeled with fertilizer mixes according to the product output composition.

Feed concentrates

Feed concentrate for cattle is composed of various nutrient sources, and there are several types of feed concentrate mixes being sold. Feed concentrate for conventional farm production is modeled in this study based on the two most widely sold formulas in Norway. However, the formulas relate to a certain level of nutrients, but which products go into the production of a specific formula to provide the given nutrient levels vary both between and within years. Variations are largely due to price fluctuations and availability of the commodities that are used in the formulas. Feed concentrate composition for the two selected types are collected and averaged for three points in time in 2007/2008. The composition is not very different with regard to which ingredients make up the main part of the mix, but there are considerable variations for some of the less important ingredients.

Feed concentrate for organic farming is modeled according to formulas from Felleskjøpet and personal information from Bioforsk økologisk by Håvard Steinshams.

Imported ingredients to the feed concentrate mixes are modeled with Ecoinvent processes, while input of feed grain from barley, oat and wheat is assumed to be produced domestically and is modeled as an input from the cereal model farms.

Energy use

Expenses on fuel use for the model farms are all assumed to be diesel. Fuel production is modeled with Ecoinvent data. Combustion emissions from farm machinery are modeled based on figures from Statistics Norway for combustion of auto diesel from stationary and mobile machinery

Energy use from fuel and electricity is provided in the accounts for the model farms.

Electricity use is modeled as Norwegian consumption mix including imports. As described earlier, organic cereal production is not included in the model farm accounts but is modeled separately for this study. Energy use for organic cereal production is estimated based on a previous study [Refsgaard et al. 1998]. Fuel use per production output is similar for conventional and organic, while electricity use comes out as approximately 40 % lower.