Energy use and Green house gas emission in organic agriculture

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Introduction

Reduction of fossil energy use has a two-fold aim namely reducing the dependence of a limited, non-renewable resource and reduction of emissions of green house gasses (GHG). Consumers interested in reducing their carbon footprint from food consumption may consider whether a shift towards eating organic foods will do the job? This involves two questions: Is organic food more energy efficient and –given that one is dedicated to eating organic – which products and which producers results in a lower GHG emission. From a farmer perspective it is interesting to know how the carbon footprint of the production may be reduced. Over time the principles for organic agriculture has included specific references to the question of reducing the use of non-renewable energy (Woodward & Vogtman, 2004) and this is still an explicit part of the objectives of the Danish organic farming movement.

It is, however, questionable to which degree these objectives have been achieved as regards the dependence on fossil energy in the present form of organic agriculture. The majority of farms still depend on fossil energy for traction and electricity and energy self-reliance seems not to be a major concern in practice. As regards fossil energy use, the major difference to conventional farming is that the rejection of chemical fertilizer reduces the indirect energy use in organic farming and that the yields are lower, thus reducing the solar energy captured in crops. However, as regards the emission of GHG the picture is more diverse and the net GHG emissions can be lower in organic agriculture compared with conventional.

The aim of this paper is thus to discuss the different perspectives of reducing energy use and GHG emissions from organic agriculture by presenting results regarding

- Different methods and results of comparison of energy use efficiency in organic agriculture
- The potential for energy savings and self-reliance in organic agriculture
- The relative importance of fossil energy use for emissions of GHG from production of different organic products
- The relative importance of different organic and conventional food items for the total GHG emission of food consumption

Energy use efficiency

Different approaches have been used to assess the energy use and efficiency of organic farming, often in comparison with conventional: Energy input per ha, input divided by output in MJ, energy use per kg of product etc. The international fertilizer society concluded in a study of organic and conventional diets that ”Organic farming requires less energy but more land than conventional farming” (Corré et al., 2003). They found that a conventional diet required app. 2000 MJ and 0.14 ha per capita in energy input while organic required app. 1300 MJ and 0.21 ha per capita.

The input of direct energy (diesel and electricity use) per ha is most often the same in organic and conventional production when comparing similar crops because the most energy consuming field operations are the same. Thus, ploughing needs app. 20-25 liters of diesel per ha and harvesting is another fuel consuming operation (Table 1). The diesel use for weed harrowing in organic fields is partly balanced by the spreading of pesticides in conventional, so the main difference in diesel use will be if more organic manure is spread on organic fields (Dalgaard et al., 2001). Fertiliser use is an indirect energy consumption into the conventional systems, which is the main cause for a higher total energy input to conventional crops compared with organic (Table 2). But this assumes that there is no indirect energy input to be attached to the manure used in the organic fields, which is questionable. Especially if the manure is from non-organic livestock and could have been used in a conventional field to replace part of the fertilizer there.

Table 1 Examples of diesel requirements for field operations (after Dalgaard et al., 2001)

FIELD OPERATIONS	DIESEL USE	
Ploughing	20-23	L per HA
Seedbed harrowing	4-6	
Traditional sowing	3	
Pesticide application, 12M	1.5	
Fertilizer application	2	
Weed harrowing	2-3	
Handling of manure	1.05	L per ton
Handling of slurry	0.41	

Table 2 Energy use in conventional and organic cereal crops in Danish dairy farms. (Refsgaard et al., 1998)

Sandy soils	MJ pr. ha	Organic	Conventional
Electricity		195	246
Diesel, manure handling		611	521
Soil preparation		1399	1568
Harvest, transport		577	577
Diesel not accounted for		1170	1208
Sum direct energy		3952	4120
Seeds		459	358
Fertilizer			3272
Pesticides			218
Liming		150	150
Machine depreciation		1968	1936
Sum indirect energy		2577	5934
Sum energy		6529	10054

Given these relations, the relative yields will determine the comparative energy efficiency in organic and conventional production. In the case of the Danish dairy farms the organic cereal needed 2.0 kg compared with 2.4 for the conventional, because the lower organic yields counterbalanced part of the difference in energy input. Pimentel et al. (1983) found 25 years ago that energy efficiency in terms of output relative to energy input was higher in organic maize where yields were almost identical while the lower energy input in potatoes was counterbalanced by lower yields (Table 3).

Table 3 Energy efficiency in organic and conventional crop production, USA 1980

	Corn		Potatoes	
	Conventional	Organic	Conventional	Organic
Energy input (1000 kcal)	6,241	3,759	15,841	8,424
("Nitrogen-fert/manure" in %)	(27)	(7)	(17)	(7)
Yelds (kg)	8,005	7,925	33,000	16,500
	27,885	27,606	20,262	10,131
Output/input (1000 kcal)	4,5	7,3	1,3	1,2

Notes: Organic crop fertilized with manure; Energy for chemical fertilizer and handling of manure included; Human labor not included

In a recent study in Turkey Gündogmus (2006) found that energy efficiency was higher in organic apricot production compared with conventional; a difference which was caused mainly by the higher indirect energy input attributed to fertilizer use. However, in these studies over a 25 year period no indirect energy use was attributed to the manure nutrient content even though a larger amount was used in the organic systems.

This conceptual and methodological question is less relevant when comparing dairy systems where the manure is an internal resource on the farm. Using the energy costs for cereals shown above and similar for fodder crops such as grass-clover (0.7 MJ per kg DM in organic vs. 2.0 in conventional) in combination with feed use and milk production from app. 30 Danish dairy farms Refsgaard et al. (1998) determined the energy price for milk to be 2.7 respectively 3.0 MJ per kg milk ab farm in organic and conventional production. In dairy production a large part of energy use is in the form of electricity in stables for hot water for washing, for milking and for cooling milk, for light, ventilation and manure moving or pumping. Moreover, increasingly machines are used for handling roughage and dispensing concentrates and there does not seem to be systematic differences in the energy use in stables between organic and conventional.

Basset Mens et al (2005) found that while *energy use per ha* was app. 25% lower in organic pig production compared with conventional and integrated production ("Label Rouge") in France, the *energy use per kg pig* produced was app. 50% higher in the organic system due to the lower stocking density.

Energy savings and self reliance

In a recent study of 20 Danish organic farms the Danish organic advisory service found a large potential for energy savings especially as regards electricity use in dairy farms. In some cases the reuse of heating generated from cooling of milk for cleaning equipment and stables and for heating in the house could reduce electricity by 15-20% and other significant energy savings would come from changing to low energy light sources. Most new dairy stables are already designed to use natural ventilation rather than energy consuming mechanical ventilation. Likewise, in organic pig production, the lower stocking density and access to outdoor runs reduces or eliminates the needs for ventilation. Therefore, Halberg et al. (2008b) found that energy use in organic pig production would not be significantly reduced when changing from a system raising pigs in concrete stables to an outdoor system using huts or tents.

Besides these relatively obvious but, nevertheless, under utilized possibilities for energy savings there is a potential for organic farms to become energy self reliant through different renewable energy sources. A knowledge synthesis initiated by DARCOF in 2005 exploring the most important aspects of energy use in Danish organic farming found that the main potential was to increase energy production, especially biogas. There are numerous possible solutions building either on wind or solar power supplementing the agricultural production or on biofuels produced as part of the farm system itself (i.e. rape oil, Rape Methyl Ester; energy crops for incineration or biogas; Halberg et al., 2008a).

Jørgensen and Dalgaard (2004) calculated that the use of app. 2.5 PJ fossil energy in the Danish organic sector on its app. 180000 ha (statistics from 2002) could be replaced by a combination of three energy sources: Biogas produced from all livestock manure (115000 Livestock units cattle plus 30000 other livestock units in 2002) plus from 20000 ha additional grass-clover; 20000 ha with oilseed rape for traction and wind turbines on 25% of the farms producing each 35000 KWh.

Presently only a fraction of the available manure is used for biogas production in the organic sector. A number of joint biogas plants were established among conventional farmers in the 1980'ties and 90'ties and presently an increasing number of large scale pig farms establish farm scale biogas production. However, this has proven more difficult in the organic sector due to the regulation because the return of digested material to an organic farm from a joint biogas plant, which receives partly conventional manure, is considered as an import of non-organic manure. Thus only relatively large individual organic farms or farms located in areas with a sufficient concentration of organic farms may invest in biogas.

Besides the existing potential for biogas production in organic livestock farms there is also an important potential in biogas and cash crop production on stockless farms. Producing grass-clover or other energy crops on cash crop farms as a supplementary energy input in biogas farms would enable an improvement in crop rotation, soil organic matter and nutrient recycling while at the same time facilitate an income from a – much needed - green manure crop in the rotation. On an experimental level Möller et al. (2006) found that producing biogas from grass-clover on 1/6 of a cash crop rotation redistributed app. 90 kg N per ha to other crops, which significantly increased wheat yields.

Using an average 39 ha Danish cash crop farm as the starting point Halberg et al. (2008a) established a model to assess the consequences of introducing extra 10% grass-clover into the crop rotation, transporting the grass 25 km to a joint biogas plant and returning the effluent with an equivalent amount of nutrients for use on the farms cash crops. Given that biogas yields of 0.35 kg CH_4 kg^{-1} organic DM delivered could be realized as found in a few tests (Fredriksson et al., 2006) the 10% grass-clover would yield enough biogas to produce 2.5 times the electricity used on the farm. Assuming that all electricity and heat is utilized for purposes where it saves fossil fuel energy, the farm will be a net energy producer (also after deduction of the 15 GJ energy used for transport of grass and de-gassed grass-effluent to and from the central biogas plant, Table 4). Similarly, introducing rapeseed on 10% of the land would yield enough cold pressed oil to replace 50-60% of the diesel used for traction.

Table 4 Energy use and production (GJ year-1) on a 39ha organic cash crop farm and two modelled alternatives. All farms export 58 tonnes cereals, 6 tonnes pulses and 9 tonnes live weight beef

Direct and indirect Energy use, GJ	**Basis**	**Rapeseed**	**Grass clover**
Diesel	129	50	124
Electricity[1]	90	92	90
Rape seed cake	1	0,2	1
Transport of grass and effluent	0	0	15
Other	0	2	1
Sum	220	145	231
Replaced energy production, GJ			
Heat produced in electricity production	0	0	111
Electricity production[1]	0	0	247
Sum	0	0	358
Net energy consumption, GJ	220	145	-127

1) The fossil energy cost for electricity used on the farms is assumed to be the same as for the replaced electricity production: 9.5 MJ kWh^{-1}. Electricity is often produced on a combined gas driven power plant, where the heat is used for houses.

Tersbøl (2007) concluded on the basis of budget calculations for 3 cash crop farms that under present price relations a farm scale biogas plant would be economic viable if additional conventional slurry were imported to the biogas plant, which would then improve the nutrient supply and yields in other cash crops. Only with 15-20% higher energy prices would an organic biogas farm scale plant be economic attractive without conventional slurry and still be dependant on energy rich waste products such as glycerine.

The relative importance of energy use for green house gas emission

While reducing fossil energy use, may be important in itself the larger objective of reducing GHG emission cannot focus on energy related CO_2 emissions alone. A large part of GHG emissions from agriculture is due to release of Methane (CH_3) from livestock and manure and Nitrous Oxide (N_2O) from fertilizer, manure and soils.

In the modeling of energy savings and GHG reduction in organic cash crop farms (Halberg et al., 2008a) the N_2O emissions as calculated using IPPC methodology contributed app. 70% of the GHG emission in CO_2 -equivalents. The results were conservative because they did not include possibly increased cereal yields and build up of SOM due to the improved crop rotation with more grass-clover. The relative importance of this aspect of Carbon-sequestration was tested in a Life Cycle Assessment (LCA) of three organic pig systems compared with the conventional pig production (Halberg et al., 2008b).

The main difference between the systems were that in organic systems all sows were free-ranged on grass-clover fields which improves welfare and introduces a better crop rotation compared with the conventional pig production with only annual crops. In the most widely used organic system in Denmark the fattening pigs are kept indoor in stables with access to a concrete sealed outdoor run, while two other systems have the growers outside all year round. Using a LCA tool the resource use and emissions through the production chain starting from soybean and fertiliser production and including feed processing, transport and on-farm processes were aggregated into categories of environmental impact per kg live weight pig delivered from the farm. The environmental impact categories considered, were eutrophication (losses of Nitrate and Phosphate), acidification (emissions of Sulforic acids, ammonia etc), global warming potential (GWP, emissions of GHG), ozone depletion, photochemical smog and land use. Selected impacts presented in Table 5 show that the Eutrophication and Acidification was lower in conventional pig production compared with organic systems. Within the organic systems free-ranging also the growers (system II) had the highest impacts in all categories due to the higher losses from the grazing area. The emission of GHG per kg pig was higher in the organic systems compared with conventional because of larger N_2O emissions and higher feed use per kg pig growth. However, this would be more than counterbalanced if the increased soil organic matter due to inclusion of grass-clover in the crop rotation was included in the calculation as Carbon-sequestration. Even with relatively conservative estimates of soil carbon sequestration the emissions of GHG would then be lower in organic compared with conventional pig production (Table 5; Halberg et al., 2008b).

Table 5 LCA results of Danish organic and conventional pork production

		Organic pig system			
Impact category	**Unit**	**I Free range sows**	**II All pigs free**	**III Tent system**	**Conventional system**
Global warming (GWP 100)	g CO_2-eq	2920	3320	2830	2700
Soil C sequestration	g CO_2-eq	-300	-400	-500	0
Acidification	g SO_2-eq	57.3	61.4	50.9	43
Eutrophication	g NO_3-eq	269	381	270	230

Note: FU: 1 kg liveweight pig ab farm

In a LCA of organic and conventional vegetable production based on farm studies Halberg et al. (2006) found a higher direct energy input in organic compared with conventional carrots due to large amounts of manure used. This in combination with a lower yield and higher N_2O emission resulted in higher GHG emissions per kg organic carrots in both intensive and less intensive production, Table 6.

Table 6 Organic and conventional carrot production

Per ha	**Conventional**	**Organic intensive**	**Organic extensive**
Input			
Fertiliser kg N	83	-	-
Fertiliser kg P	48	-	-
Manure, kg N	-	270	135
Electricity, kWh	5118	518	518
Diesel, MJ	14981	18758	15768
Yelds			
Carrots, ton	61,6	52,8	40,0
GHG emission, g kg^{-1}	122	188	234

The higher GHG emission from organic carrots will, however, be of minor importance for the overall effect of an organic vs. conventional diet, because the GHG emission per kg field vegetables in any case is a factor 100 lower than for livestock products (Halberg et al., 2006).

Conclusion

Improving energy efficiency and self-reliance is but one of many principles and objectives in organic agriculture and should therefore be balanced against other objectives such as improving nutrient recycling, soil fertility, animal welfare and biodiversity. In these aspects organic agriculture has an advantage and it is therefore a major challenge to improve energy use efficiency and self reliance without compromising the other objectives. More focus seems to be needed in order to reduce dependence on fossil energy sources and combine renewable energy production with food production in organic farming. Electricity savings is a straight forward solution and many dairy farms could save more than 25% by using existing technologies. Biogas production is another well known technology, which is underused in organic agriculture partly because of organisational barriers to establish joint biogas plants in a setting where both electricity and heat generated may be used efficiently.

Contrary to this, reductions in field operations for the sake of saving fuel are unlikely to give a significant improvement from an energetic point of view especially if it implies a reduction in yields per hectare.

Contrary, the focus should be on sustaining high yields and on the proper use of organic material in harvested yields and crop residues for both soil fertility and bio-energy. A combination of bio-gas production from livestock and grassland is suggested as a way to achieve multiple goals of improving energy production, soil organic matter, crop rotation and nutrient redistribution in a large scale conversion to organic agriculture. The improvement in soil organic matter arising from crop rotations with increased grass-clover will increase carbon sequestration but more studies are needed to determine whether this would be counterbalanced by increased emissions of Nitrous oxides.

From a consumer perspective, an efficient way of reducing the GHG emissions (carbon footprint) from food consumption is to replace the intake of meat and dairy products with plant protein and food energy not coming from glass house production. Given that many consumers wish to consume some amount of animal products, many results indicate that organic is a good choice. As regards plant products, organically grown vegetables with a relatively high energy input compared to yields (heated glasshouses or field grown vegetables using many field operations and manure input) risk having a larger GHG emission per kg compared with conventional. However, the carbon footprint per kg of field grown vegetables and cereals is low compared with livestock and glass house products and organic cereals will often leave a lower carbon footprint compared with conventional. Therefore, with the right combination of protein and energy sources and by limiting air fright it is possible to compose an organic diet with relatively low carbon footprint. If the organic sector decides to engage seriously in a development towards energy self reliance and crop rotations with carbon sequestration without increasing the N_2O emissions the choice of organic products may in time be a more convincing choice.

References

Basset-Mens C, van der Werf H.M.G, 2005. Scenario-based environmental assessment of farming systems: the case of pig production in France. Agric. Ecosyst. Environ. 105(1-2), 127-144.

Corré W.J., Schröder J.J., Verhagen A., 2003. Energy Use in Conventional and Organic Farming Systems. The International Fertiliser Society, Proceeding 511. Available on-line: http://www.fertiliser-society.org/Proceedings/UK/Prc511.HTM

Dalgaard T., Halberg N., Porter J.R., 2001. A model for fossil energy use in Danish agriculture used to compare organic and conventional farming. Agriculture, Ecosystems & Environment 87 (1): 51-65.

Fredriksson H., Baky A., Bernesson S., Nordberg Å., Norén O., Hansson P.-A., 2006. Use of on-farm produced biofuels on organic farms – Evaluation of energy balances and environmental loads for three possible fuels. Agricultural Systems 89, 184-203.

Gündoğmuş E., 2006. Energy use on organic farming: A comparative analysis on organic versus conventional apricot production on small holdings in Turkey. Energy Conversion and Management 47 (18-19) 3351-3359

Grönroos J., Seppälä J., Voutilainen P., Seuri P., Koikkalainen K., 2006. Energy use in conventional and organic milk and rye bread production in Finland. Agriculture, Ecosystems & Environment 117, 109-118.

Halberg N., Dalgaard R., Olesen J.E., Dalgaard T., 2008a. Energy self-reliance, net-energy production and GHG emissions in Danish organic cash crop farms. Renewable Agriculture and Food Systems, 23(1) 30-37.

Halberg N., Dalgaard R., Rasmussen M.D., 2006. Miljøvurdering af konventionel og økologisk avl af grøntsager - Livscyklusvurdering af produktion i væksthuse og på friland: Tomater, agurker, løg, gulerødder. (Life Cycle Assessment of Conventional and organic vegetable production). Arbejdsrapport fra Miljøstyrelsen no. 5. Available online: http://orgprints.org/13085/

Halberg N., Hermansen J.E., Kristensen I.S., Eriksen J. Tvedegaard N. 2008b. Comparative environmental assessment of three systems for organic pig production in Denmark. ISOFAR Conference Series. Proceedings. Organic Agriculture in Asia. 13-14 March 2008. Dankook University, Korea. 249-261.

Jørgensen U., Dalgaard T., 2004. Energi i økologisk jordbrug. Reduktion af fossilt energiforbrug og produktion af vedvarende energi. [Energy in organic farming. Reduction of fossil energy use and production of bio-energy]. FØJO-rapport 19, 165 pp. Available on-line: http://www.foejo.dk/publikation/rapport/Rap_19.pdf

Möller K., Stinner W., Leithold G., 2006. Biogas in organic agriculture: Effects on yields, nutrient uptake and environmental parameters of the cropping system. Paper presented at Joint Organic Congress, Odense, Denmark, May 30-31, 2006. Available on-line: http://www.orgprints.org/7223/

Tersbøl M., 2007. Challenges of organic crop production – biogas can be the solution. NJF 23rd Congress. Trends and Perspectives in Agriculture. Copenhagen, June 26-29, 2007. Pp 201-202.

Pimentel D., Berardi G., Fast S., 1983. Energy efficiency of farming systems: Organic and conventional agriculture. Agriculture, Ecosystems & Environment 9 (4) 359-372.

Refsgaard K. Halberg N., Kristensen E.S., 1998. Energy Utilization in Crop and Dairy Production in Organic and Conventional Livestock Production Systems. Agricultural Systems, 57 (4) 599-630.

Woodward L., Vogtman H., 2004. IFOAM's organic principles. IFOAM. Ecology and Farming, May August 2004, 24-26.