CEESA Bio-energy potentials from agriculture in Denmark under assumptions of organic farming and dietary changes

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Introduction

This paper provides estimates of bio-energy potentials from Danish agriculture for a range of scenarios assuming either a conversion to organic farming or enacting dietary changes in the Danish population.

Organic farming

In Denmark organic agriculture has seen a substantial increase over the last few decades. From a market share of ~0 % before 1990 organic products now (2007) cover ~5.8 % of the turnover generated food commodities (Alroe & Halberg 2008).

Three different scenarios for organic farming are explored. The scenarios are

a) No import of feed is possible and the level of meat production is kept as high as possible.
b) Unlimited import of feed is possible and the level of meat production is approximately the same as the current.
c) Organic farming without animal production.

Scenarios a) and b) primarily builds on scenarios developed under the work of the Bichel committee. Scenario c) builds on simplified assumptions regarding the change in crop rotation required, when converting from conventional to organic farming.

Change of diet

It has been proposed that the average Danish diet may be problematic in terms of the population's general health, but also that the diet has an unnecessary negative impact on the environment partly due to the fact that producing a given amount of proteins and energy via meat takes up more land than producing it via vegetable foods. Here it is explored whether a change in the current diet could have an impact on the bio energy potential from Danish agriculture. The assumption behind is that agricultural land liberated due to a change in diet is used for growing willow for energy.

Two scenarios are explored:

d) The diet is changed from the current to a diet recommended by Danmarks Foedevareforskning.
e) The diet is changed from the current to a lacto-ovo vegetarian diet (meat and fish is substituted with cheese and egg)

Organic agriculture

Organic agriculture is different from conventional agriculture in many ways. The differences most significantly affecting the bio-energy potential are, in prioritised sequence, a) different crop rotation, b) in general lower yields and c) the increased use of straw for bedding.

Different crop rotation
As organic agriculture cannot use chemical components in plant protection and industrial fertilisers the crop rotation must change in order to more significantly recycle nutrients (avoid leaching), capture nutrients from the atmosphere and increase the protective benefits one crop may have on a subsequent crop. In current agriculture the average crop rotation consists of 55% cereals, 27 % clover, grass and green fodder, 6% rape seed, 0.2 % pulses and 3 % beet (Danmarks Statistik 2009). The remainder is covered by fruits, vegetables and other small crops.

A typical organic crop rotation is based on a 5 year cycle (fem marks drift) and would be made up of 35 % cereals, 47 % clover, grass and green fodder, 2 % Rape seed, 1 % pulses (Askegaard et al 2008). The main changes caused by a conversion from conventional to organic farming is a decrease in the production of cereals, rape seed and beet and an increase in the production of grass, clover and greed fodder.

Crop yield
In organic farming crop yields are generally lower as compared to conventional farming. Askegaard et al (2008) has found that organic spring cereals yield 63-87 % of conventional spring cereals. Corresponding figures are for winter cereals 50-73 %, for peas (pulses) 69-85 % and for winter rape 67-75 %.

Straw for bedding
In organic animal husbandry it is required that the animals are provided some sort of bedding. This requirement doesn't exist in conventional farming although it is widely used for the sake of animal well fare. Bedding material is typically straw from cereals. In 2006 631 Mio kg out of a total production of 5239 Mio kg was used for bedding (Danmarks Statistik 2009), corresponding to 12 %.

For ruminants and pigs respectively the average consumption of straw for bedding is estimated to 2000 kg pr animal produced (Madsen & Lund 2000) and 1445 (Tvedegaard 2005) kg pr sow produced.

Agricultural production
Table 1 show the current (1996) and projected use of agricultural land under the assumption of organic farming scenarios a) and b). The changes in land use generally reflect the above mentioned changes in crop rotation. Set aside land, which is included in [Grass (not in rotation)], is under the organic scenarios assumed to be zero ha.

Table 1. Current use of agricultural land and use under the assumption of scenario a and b. From Bichel-udvalget (2009)

1000 ha	Danish agriculture 1996	No feed import (scenario a)	Unlimited feed import (scenario b)
Cereals	1545	1075	1221
Pulses	73	183	154
Rape seed	109	118	0
Seeds	61	27	27
Grass (in rotation)	370	973	973
Fodder beet	41	55	55
Sugar beet	70	45	45
Potato	43	13	13
Vegetables	7	11	11
Fruits, berries	12	16	16
Grass (not in rotation)	384	200	200

Due to decreased are with cereal and reduced yields a predominant change in agricultural production is the total production of cereals, which drop from close to 10 billion SFU (Scandinavian feed units = foderenheder in Danish, FE) to somewhere between 3.7 and 4.8 billion SFU. Other remarkable changes are the increase in grass and green fodder production and the decrease in potato production.
Regarding meat production scenario a), where feed import is not allowed cannot sustain the current production of pork and poultry.

Table 2. Current production of agricultural produce and potential organic production under the assumptions of scenario a) and b). From Bichel-udvalget (1999)
[1)] SFU (foderenhed, FE) Scandinavian feed unit; the feed value of 1 kg rye.

	Unit	Danish agriculture 1996	No feed import (scenario a)	Unlimited feed import (scenario b)
Cereals	Mio SFU[1)]	9850	3678	4785
Grass and green fodder	Mio SFU	3269	5311	5060
Fodder beet	Mio SFU	440	537	537
Rape seed	Mio kg	251	271	0
Seeds	Mio kg	64	13	13
Potatoes	Mio kg	1617	327	327
Sugar	Mio kg	493	225	225
Vegetables	Mio kg	291	291	291
Fruits, berries	Mio kg	61	61	61
Milk	Mio kg	4650	4650	4650
Beef	Mio kg	198	202	190
Pork and poultry	Mio kg	1773	531	1773
Eggs	Mio kg	88	88	88

Bio-energy potential
The bio-energy potential from agricultural primary production almost exclusively relies on straw from cereals. Bio gas from manure is the primary secondary source. Under the assumption that organic and conventional agriculture exhibit similar harvest indices table 3 show the estimated bio-energy potential from scenario a) and b), based on Bichel-udvalget (1999).

Table 3. Estimated bio-energy potential from organic agriculture under the assumptions of organic farming scenario a) and b). Straw to grain yield ratio based on Danmarks Statistik (2009). The amount of straw used for bedding is based on the ratio between meat production and number of animals produced (Danmarks Statistik 2009) and on Madsen & Lund (2000), Tvedegaard (2005). Biogas potential is based on a ratio between produced meat and methane potential (Danmarks Statistik 2009, Joergensen et al. 2008). It is further assumed that 70 % of the manure can be collected (Dalgaard et al. 2004) the rest is deposited on the fields.

	Unit	No feed import (scenario a)	Unlimited feed import (scenario b)
Straw from cereals	Mio kg	1398	1818
	PJ	20.3	26.4
Straw used for bedding	Mio kg	1798	2134
Straw available for energy	Mio kg	0	0
Biogas (methane)	Mio m^3	165	440
	PJ	5.9	15.8

Organic agriculture without animal production

Under the assumption that organic agriculture can be managed without animals (scenario c) the change in crop rotation will lead to cereal production on 0.94 Mha compared to the current 1.48 Mha. With reduced yields as compared to conventional yields 1.956 Mkg straw can be produced. Furthermore 1.21 Mha will be covered with clover grass, which in turn can be digested before the nutrients are recycled to the soil. Moeller et al. (2004) estimate that 1 ha of grass can yield a net of 1700 m^3 methane corresponding to 61 GJ ha^{-1}*yr.

Table 4. Estimated bio-energy potential from organic agriculture without animal production. Calculated from Askegaard et al. (2008), Moeller et al. (2004).

	Unit	No animals (scenario a)
Straw from cereals	Mio kg	1.956
	PJ	28.4
Biogas (methane) from grass/clover	Mio m^3	2057
	PJ	74.0

Dietary changes

The estimation of the impact on bio-energy potentials from a change in diets is not straight forward. It is not just a matter of feeding people the feed currently used for livestock. Based on FAO statistics (FAO 2010) a food balance for Denmark is made (Table 5). The total production of agricultural produce is 20.6 Mt and the consumption of the same products is 5.8 Mt. As such domestic consumption of food corresponds to 28.3 % of the domestic production from agriculture.

Table 5. Food balance 2005 for Denmark; based on FAO (2010).

2005	Production	Import quantity	Stock variation	Export quantity	Domestic supply quantity	Feed	Seed	Processing	Food
	1000 tonnes								
Cereals	9283	1233	-587	1209	8719	7223	277	158	722
Starchy roots	1576	167	76	168	1651	69	100	833	411
Sugar & sweeteners	636	226	24	329	558	1	0	0	276
Pulses	53	15	19	20	67	57	3	0	5
Oil crops	342	298	-2	62	577	84	6	474	10
Vegetable oils	168	553	10	389	342	0	0	11	33
Vegetables	255	378	0	70	562	0	0	0	529
Fruits	73	861	20	149	805	0	0	11	779
Alcoholic beverages	924	288	-67	433	711	0	0	0	650
Meat	2122	259	-226	1593	562	0	0	7	546
Offals	93	21	0	193	-78	1	0	0	6
Animal fats	362	184	-2	304	240	49	0	11	143
Eggs	80	45	0	11	114	0	11	0	103
Milk	4584	748	-198	3057	2077	375	0	0	1608
Total	20551								5821

Danish agriculture covers an area of 2.71 Mha (Danmarks Statistik 2010). If the Danish consumption is assumed produced on 28.3 % of the current agricultural area 0.77 Mha would be required.

Saxe et al. (2006) has estimated the change in environmental impact from changes in the Danish diet. They find that a transition from current average diet to a diet recommended by Danmarks Foedevareforskning can reduce the land requirements with 16 % and correspondingly a transition to a lacto-ovo vegetarian diet reduce the pressure on land with 30 – 49 %. These figures correspond to other findings. Pimentel & Pimentel (2003) finds that vegetarian diets require 20-30% less land than meat based diets. Peters et al. (2007) finds for the state of New York, US that reducing the intake of meat from 254 g day-1 capita-1 to a vegetarian diet reduces the land requirements with 62 %. The average intake of meat in Denmark is ~101 g day-1 capita-1 (FAO 2010).

Table 6 show the estimated bio-energy potential under the assumption that the entire population switch to either a more healthy diet in accordance with the recommendations for Danmarks Foedevareforskning or to a lacto-ovo vegetarian diet (Saxe et al. 2006). No statistics are found on how many people in Denmark already follow a lacto-ovo vegetarian diet; it is assumed the number is insignificant. Dietary changes only has an impact on the proportion of agriculture that produces food for the Danish population, whereas as the remainder of agriculture remains unaffected. Probably the main change in agricultural production will be seen in the production of pig meat. As pigs predominantly are fed with grain it is assumed that 75 % of the area affected by dietary changes will be cereals. Thus a decrease in the production of straw must expected.

Table 6. Changes in bio-energy potential from a change in dietary habits. 1) Yield estimates based on Danmarks Statistik (2010), LHV = 14.5 MJ kg-1 (Energistyrelsen 2010). Yield expressed at 15 % moisture content. 2) Yield estimates and LHV = 16.5 MJ kg-1 based on Borjesson (2006). Yield expressed as dry weight. 3) Estimated yields under the assumption of improved plant performance due to selection and engineering.

		Yield	Recommended diet (scenario d)	Lact-ovo vegetarian diet (scenario e)
Area released	Ha		122880	230400
Reduced straw yield [1)]	Mkg	3266 kg ha^{-1} yr^{-1}	301	564
	PJ		4.4	8.2
Energy crop (2010) [2)]	Mkg	9390 kg ha^{-1} yr^{-1}	1154	2163
	PJ		19.0	35.7
Net supply (2010)	PJ		14.6	27.5
Energy crop (2030) [3)]	Mkg	15000 kg ha^{-1} yr^{-1}	1843	3456
	PJ		30.4	57.0
Net supply (2030)	PJ		26	48.8
Energy crop (2050) [3)]	Mkg	20000 kg ha^{-1} yr^{-1}	2456	4608
	PJ		40.6	76.0
Net supply (2050)	PJ		36.2	67.8

Precautions

Precautions must be taken in the further analysis of these data. It is assumed that all produce is collected and processed. In current agricultural practice that is not the case. Furthermore the (very) long term sustainability of the scenarios is questionable as all of them include a massive harvest of carbon from the soil. The actual carrying capacity of Danish soils is not known and is a very specific interplay between soil type, crop, climate and current state of the soil (utilisation history).

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