Comparing food production and land use for organic and conventional agriculture in Denmark

Summary

This analysis combines research on yield gaps, land use and food production to compare the number of people fed per hectare by organic and conventional agriculture in Denmark. It suggests that the different land uses in the two systems currently balance the effect of yield differences – organic farms use a proportionally higher amount of their land for growing crops for human consumption, which compensates for the lower yields. This challenges the assumption that organic agriculture produces less food per land area, and supports the claim that consumption patterns are the key driver of land footprints in agriculture. Studies concerning future food production should focus on consumption patterns and the sources of animal fodder.

Background

Since crop yields from organic agriculture are generally lower than from conventional agriculture (Seufert et al. 2012), it is often assumed that the land footprint of organic agriculture is larger than that of conventional. For example, news media have presented organic agriculture as "inefficient" (Tran 2009), "far less productive" (Waugh 2013), and "[using] far more land, which is harmful to the planet" (Gollayan 2013). This is seen as a major concern for the viability of organic agriculture in light of concerns over environmental impacts and food security (Johnson 2015; Oremus 2012). However, the food production and environmental impacts of agriculture also depend on land use (Cassidy et al. 2013, Lacour et al. 2018, Mertens et al. 2019), so a realistic comparison between agricultural methods must account for differences in land use as well as crop yields. This report therefore aims to assess the current land use and food production of organic and conventional agriculture in Denmark.

Land area for the purposes of this analysis means the area of agricultural land on which organic and conventional agricultural production in Denmark is based. This analysis aims to assess the efficiency of organic and conventional agriculture as whole systems, so the whole land area is counted. This includes areas left fallow and land used for purposes such as seed production, and overseas areas used for growing feed for Danish livestock.

People fed per hectare is represented by the number of average calorie and protein intakes provided by all food for human consumption produced by an agricultural system (after Cassidy et al. 2013).

Land use

In both organic and conventional agriculture systems, producing fodder for Denmark's large livestock sector requires a large amount of land. The amount of land used for producing plant-based foods for human consumption is relatively small. Regarding livestock production, organic systems can be characterised as more extensive, with a higher proportion of cattle to other animals, and a relatively high use of grass for fodder. Conventional livestock production is more intensive, involving large numbers of pigs raised indoors and fed mostly on cereals and fodder crops such as soy. Fodder for animals is also imported from overseas, especially soy, which is an important source of protein needed for weight gain in animals.

Most of the land used by Danish agriculture therefore falls into three important categories: grass and pasture, cereals (of which approximately 87% of production is used as fodder), and non-cereal fodder crops (crops used to feed animals, other than grass or cereals). Of the remaining land, most is used for "industrial" crops – crops that are used for processed food products such as sugar, or industrial uses such as biodiesel). The next largest category land use involves no food production at all, comprising fallow land, land set aside for nature, decorative crops such as flowers and Christmas trees, and the gardening industry. Finally, a small fraction is used for producing vegetables (such as potatoes, carrots and cabbages) and fruits (such as apples). The relative shares of land for these categories are presented as "land use profiles" in Figures 1 & 2.

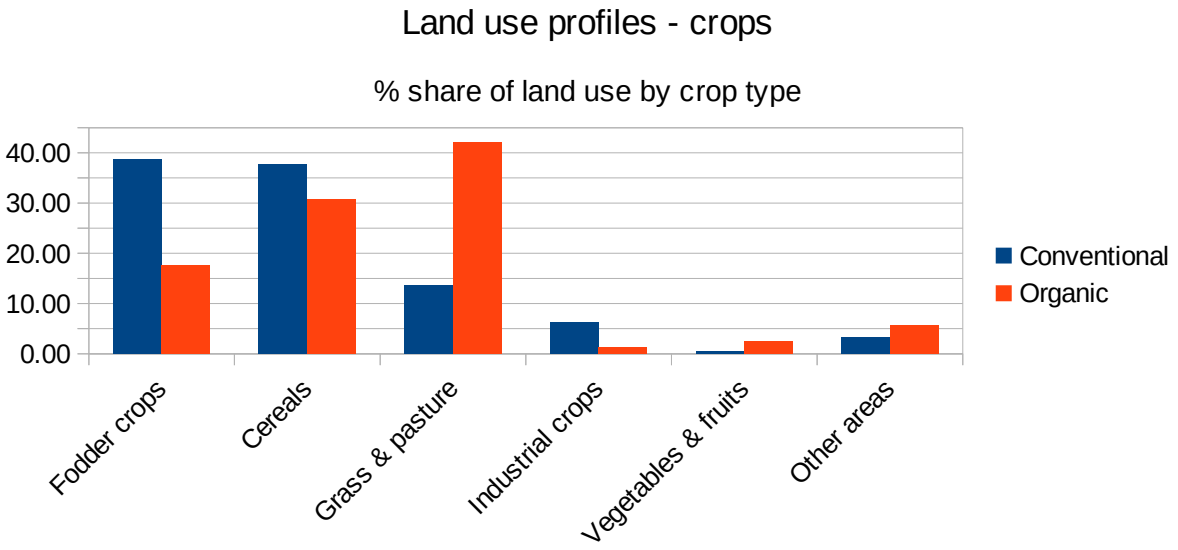

Figure 1 – land use by crop. Crop types are explained below:

- Fodder crops – crops fed to animals (other than grass and cereals), including those grown overseas and imported to Denmark (e.g. soy).
- Cereals – grain crops such as barley, wheat, oats and rye.
- Grass and pasture – either as part of a rotation or permanent pasture areas.
- Industrial crops – used for processed food products (e.g. sugar), or industrial uses (e.g. biodiesel)
- Vegetables and fruits – for human consumption (e.g. potatoes, cabbages).
- Other areas – areas left fallow or used for decorative crops such as Christmas trees.

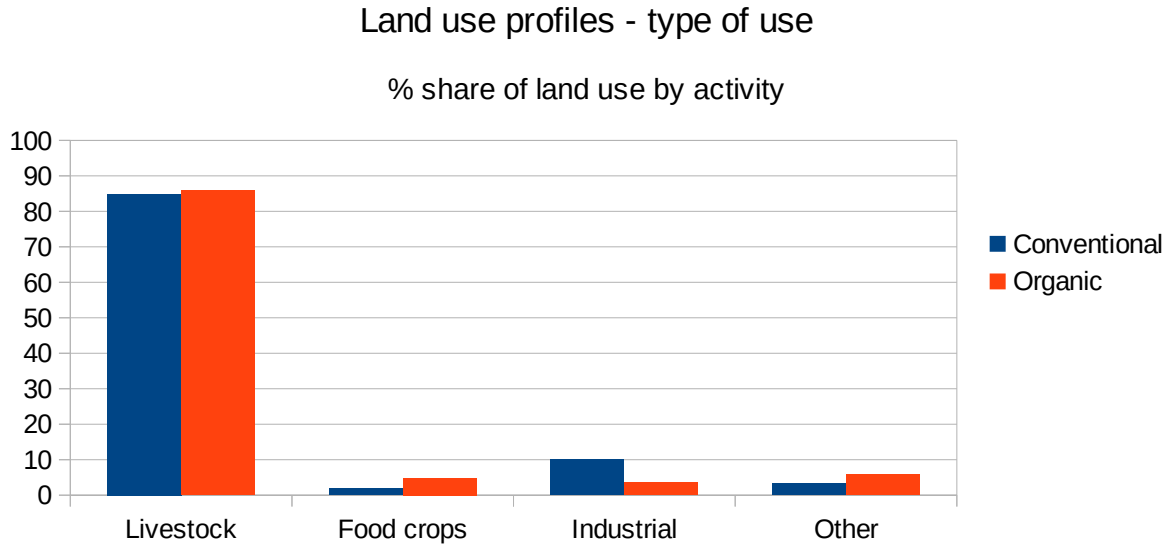

Figure 2 – land use by type. Land use types are explained below:

- Livestock – all land used for feeding and housing livestock.
- Food crops – all crops for direct human consumption, including cereals, vegetables and fruits.
- Industrial – all crops used for processed food products (e.g. sugar), or industrial uses (e.g. biodiesel)
- Other - areas left fallow or used for decorative crops such as Christmas trees.

Food production

The amounts of food produced in each system are presented in Tables 1 and 2.

Conventional food production	Production (m. kg)	2700 kCal diets	% of total conv. calories	56g protein diets	% of total conv. protein
Cereals	381.51	1316993	12.85	1978477	8.13
Potatoes	420.47	328526	3.20	411419	1.69
Vegetables	260.23	102455	1.00	188425	0.77
Fruits	42.35	23334	0.23	13467	0.06
Sugar	64.21	575950	5.62	0	0.00
Oil	278.91	1089587	10.63	0	0.00
All plant-based		*3436845*	*33.52*	*2591788*	*10.65*
Pork	1267.39	3176513	30.98	11160969	45.87
Poultry	149.41	216800	2.11	1315744	5.41
Beef	69.28	173639	1.69	677886	2.79
Mutton	1.05	3516	0.03	7140	0.03
Milk	4957.48	3169165	30.91	8246297	33.89
Eggs	55.00	76459	0.75	330969	1.36
All livestock-based		*6816092*	*66.48*	*21739005*	*89.35*
All products		10252937		24330793	

Table 1 – food production from conventional agriculture in Denmark. The number of "2700 kCal diets" represents the number of sets of 2700 kilocalories per day (the recommended adult intake) provided (Cassidy et al. 2013). The number of "56g protein diets" measures the same thing for protein.

Organic food production	Production (m. kg)	2700 kCal diets	% of total organic calories	56 g protein diets	% of total organic protein
Cereals	27.40	95698	11.30	142094	6.55
Potatoes	63.91	49935	5.90	62534	2.88
Vegetables	83.28	32788	3.87	60301	2.78
Fruits	13.27	7312	0.86	4220	0.19
Sugar	1.24	11141	1.32	0	0.00
Vegetable oil	1.24	4830	0.57	0	0.00
All plant-based		*201703*	*23.82*	*269149*	*12.42*
Pork	59.80	149879	17.70	526614	24.29
Poultry	2.10	3047	0.36	18493	0.85
Beef	12.08	30277	3.58	118200	5.45
Mutton	0.09	301	0.04	612	0.03
Milk	662.74	430394	50.84	1102405	50.85

Eggs	22.00	31030	3.67	132387	6.11
All livestock-based		*644929*	*76.18*	*1898712*	*87.58*
All products		**846632**		**2167861**	

Table 2 – food production from organic agriculture in Denmark. The number of "2700 kCal diets" represents the number of sets of 2700 kilocalories per day (the recommended adult intake) provided (Cassidy et al. 2013). The number of "56g protein diets" measures the same thing for protein.

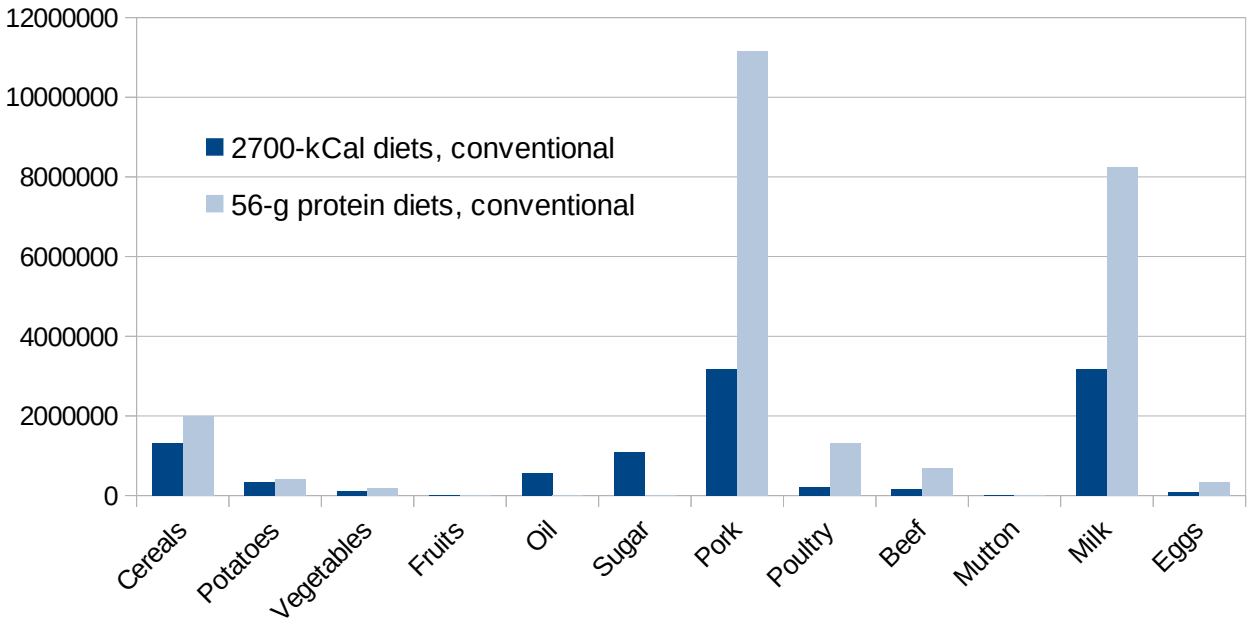

Figure 3 – calorie and protein profile for conventional agriculture. The columns represent the percentage of total calorie or protein output (for this agricultural system) that comes from the various food products.

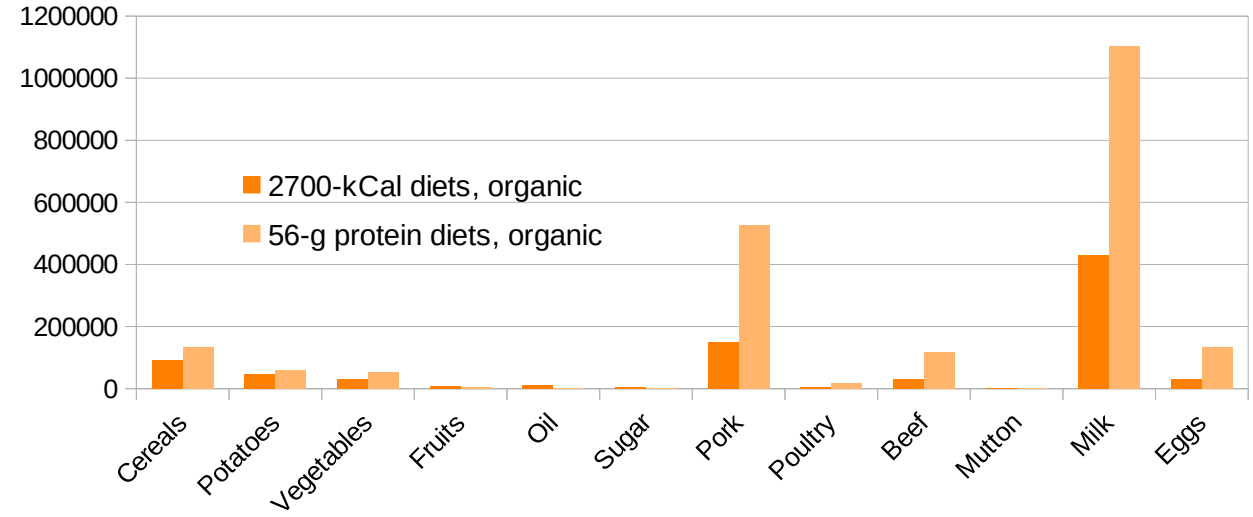

Figure 4 – calorie and protein profile for organic agriculture. The columns represent the percentage of total calorie or protein output (for this agricultural system) that comes from the various food products.

Both organic and conventional systems produce large amounts of protein compared to calories (Figures 3 & 4). The protein production is especially high in animal products. Animal products are also the major source of calories in both systems. Plant-based foods contribute relatively little to calorie output, and still less to protein; most of this is from cereals, although a considerable portion of calories in conventional agriculture comes from vegetable oil and sugar. Within animal products, it is evident that conventional system has an especially high output of pork, while the organic livestock industry has a higher share of milk in its food profile.

People fed per hectare

The estimated organic and conventional food production can then compared to the land area used by each system to determine the number of people fed per hectare (Table 3).

	People fed per hectare (calories), conventional	People fed per hectare (protein), conventional	People fed per hectare (calories), organic	People fed per hectare (protein), organic
Food crops	27.01	39.52	13.20	19.13
Livestock	2.29	7.31	2.56	7.53
Total	**2.93**	**6.95**	**2.89**	**7.39**

Table 3 – people fed per hectare by conventional and organic agriculture in Denmark.

Plant-based foods provide the most calories and protein per hectare. Animal products are land-demanding sources of food, especially calories, compared to food crops. The totals are closer to the numbers for livestock than food crops because livestock production is the predominant land use (see Figure 2). Compared to conventional agriculture, organic agriculture feeds almost as many (98.58%) people in terms of calories, and more (106.38%) people in terms of protein.

Sources of calories and protein

The large share of food from livestock products reflects the specialisation of Danish agriculture towards pork (especially in conventional farms) and milk (especially organic). The large difference in people fed per hectare between animal and plant products can be explained by the land requirement for producing animal feed. Despite the noted efficiency of the Danish livestock industry (Claxton 2018, Strak 2016), it is a much less efficient use of land than plant products. This is due to the fact converting the food energy and protein in fodder into meat via an animal's digestive system involves significant losses (through metabolism, manure, and the growth of inedible tissues and organs), meaning that the calorie and protein output of animal products to markets is much lower than the calorie and protein input of fodder to the livestock system (Shepon et al. 2016).

Differences between conventional and organic production

The number of people fed by organic agriculture is higher than yield gaps would lead us to expect. Despite average organic yields from crops being about 80% of conventional yields, the organic system in Denmark as a whole feeds 98-106% as many people per hectare. To understand how this is possible, we must compare organic and conventional land uses.

The reason organic agriculture fares better when comparing protein than calories may be the relatively high land use for oil and sugar production in conventional agriculture (see appendix). These products are high in calories but contain no protein.

Yield gaps do reduce the productivity of organic crops; although the average differences vary by crop, some of the biggest yield gaps occur in crops that are widely grown in Denmark, such as barley. The

yield gaps used here are approximate and estimates of the average yield gaps vary; for example, Ponisio et al. (2015) estimated yield gaps as being smaller overall than Seufert et al. (2012); if this analysis is repeated with the yield gaps reported by the former, the number of people fed by organic agriculture increases by 1.73 %. Yield gaps could also change in the future since they tend to lessen over time as benefits of organic management accrue (Schrama et al. 2018).

In food crops, conventional agriculture performs better than organic, due at least partly to the yield gap. Organic production of calories and protein from food crops is comparatively low, but this might be caused by a higher land use for fruits and vegetables, which tend to provide less calories and protein than cereal crops. In real terms, vegetables are more important to the diet than the simple number of calories they contain, suggesting a flaw in this method for assessing human dietary contributions (see *Dietary components* below). Although the number of people fed per hectare by organic food crops is relatively low, this is partly compensated by the larger share of land used for food crops in organic agriculture – since it is more productive than land used for livestock, a higher share of land for food crops increases the number of people fed per hectare. The larger share of organic land for food crops is due to the more widespread use of land for industrial purposes (such as ethanol and bio-diesel production) in conventional agriculture. Organic farms generally supply food markets, so do not use land in this way, instead using a larger share of its land for producing food crops.

For livestock production, organic agriculture is slightly more productive in both calories and protein. This is possibly due to differences in land use efficiency for different animal products – milk and eggs, which are more heavily represented in organic agriculture, are the most land-efficient animal products (Cassidy et al. 2013, Shepon et al. 2016). Also, organic animals are fed partly on crops with a small yield difference (such as legumes), so organic agriculture avoid some of the most severe yield gaps (such as in wheat).

Dietary components for measuring food production

Although estimating the number of people fed per hectare from total calorie and protein production is a useful way of quickly comparing land uses, it is a flawed measure of food production. Products such as sugar and vegetable oil contain large amounts of calories, but are not required in the diet in the same quantities as vegetables and cereals, so their contribution to the number of people "fed" is questionable. It could be argued that cereals, vegetables, fruits, meats, milk and eggs more accurately represent what most people would consider to be "food"; if the analysis is adjusted to exclude oil and sugar as food sources, organic agriculture feeds more people per hectare in terms of calories as well as protein.

The production of protein may be a more useful comparison than that of calories, since it avoids the problem of a few calorie-dense crops skewing the results. However, the protein content of food differs in quality and digestibility; for example, most cereals are deficient in the amino acid lysine, while animal products are "complete" proteins. Although plant proteins can can be combined to provide an adequate intake (Young & Pellett 1994), differences in protein quality make it difficult to to directly compare products based on their protein contents alone. It is also possible that organic crops may have lower protein contents than conventional ones (Calback & Sumption 2016).

Towards a land-efficient agriculture

Other studies modelling the production impacts of widespread conversion to organic agriculture suggest that more land would be needed unless the types of land use in agriculture were significantly changed (Kniss et al. 2016, Smith et al. 2018). These studies could be said to take a "ground-up"

approach, in which production is modelled based on land area and predicted yield. It is also possible to approach land efficiency from a diet-based perspective, in which the average consumer intakes of products are traced back to the land required to produce them. This method reveals consumption patterns as key drivers of land efficiency, especially the consumption of animal products (Audsley et al. 2011, de Ruiter et al. 2017, Mertens et al. 2019). When comparing organic to conventional land use in Europe from a diet-based perspective, results vary; some report that diets based on organic foods require less land (Baroni et al. 2006), while others report that they require more (Treu et al. 2017). However, it is clear that the land use efficiency of food production depends more strongly on what is being farmed than on how the farm is run.

This conclusion is supported by the results of the analysis. Overall the organic sector in Denmark currently delivers more of its calories & protein towards human consumption, since it involves less of the most inefficient livestock production chains and industrial uses. Therefore, despite the lower yields from some crops, the number of people fed by organic agriculture per hectare is similar to that of conventional.

If the organic agricultural area in Denmark were expanded, the impact on Danish food production would depend on the use of the new organic land. Even precise information on yield gaps would not be very informative to model future food production if the land uses were not accounted for. Land use will in turn depend on the demand from markets. This analysis therefore supports the findings of Lacour et al. (2018) – land use efficiency in both organic and conventional agriculture depends on diet, with plant-based foods generally being the least land-demanding way of feeding people. Organic agriculture may have an advantage in this regard, since people who buy organic products tend to consume more plant-based foods than average (Kesse-Guyot et al. 2013).

Next steps in research

Health advice suggests that most westerners would benefit from a reduced intake of animal products, and an increased intake of fruit and vegetables (EAT-Lancet Commission 2019). These recommended intakes, along with average intakes for various types of consumers, would allow an analysis of land use for food production in terms of diets. This would involve estimating land use for each product consumed in the reference diets making for a much more complex project which would have to consider overseas food production as well as in Denmark. This would allow a more detailed and robust analysis of land use, and also allow us to compare the effects of increasing amounts of organic foods in people's diets. Another important research area is the possibility of new sources of animal feed, including improved grass and legume varieties, and novel protein sources (The Danish Bioeconomy Panel 2018).

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