MatLust

Milk and plant-based alternatives — an environmental assessment

BRIEF • December 2020

EUROPEAN UNION
European Regional Development Fund

Södertälje kommun

SÖDERTÄLJE SCIENCE PARK

KTH VETENSKAP OCH KONST

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This brief compares the environmental effects of dairy products and plant-based alternatives, mainly oats and soy, to dairy under Swedish conditions. It also discusses, where relevant, the differences between organic and conventional production.[1]

Table of contents

Key conclusion

The food system is dynamic and one cannot deduct the full environmental impact of choices of consumption from the results of lifecycle assessments. The choice between milk and plant-based alternatives is less important than how the food system is designed and how they are produced. There are no reasons to position consumption of milk and oat or soy as mutually exclusive.

Origin, production and market

Sweden is part of the dairy belt and dairy production and the consumption of milk products and beef has been an important feature of the agriculture and food system for centuries. Swedish dairy production is comparatively intensive, and the average size of farms is growing rapidly. Meanwhile, fifteen percent of the milk in Sweden is organically produced. Production of milk in Sweden peaked at almost 5 million tons 1949, 700 kg per person. Today, the production is less than half that and consumption of milk has steadily decreased. In 2016, the average consumer drank 79 l of milk, 34 l of cured milk, ate 20 kg of cheese, 13 kg of cream and 2.5 kg of butter.[2 3]

Global milk production is in the range of 100 l per person. It is produced in systems ranging from pastoralists who get some 500 l per cow (after the calf has taken its share) to huge industrial dairy companies with an average yield per cow exceeding 10,000 l. Consumption has decreased in the traditional dairy belt while it has increased in countries where people drank little milk previously.[4]

Oats was the most important cereal grain in Sweden in the 19th century and huge quantities were exported to England for use as horse fodder. Today it constitutes only 13 percent of the grain harvest. Around 15 percent of the oats are organically produced.[5] Globally it is a minor cereal grain and world production has declined by 57 percent since 1962.[6] Oat drink (as produced by Oatly) is made of oats and rapeseed (canola) oil. Of the unshelled oats, 63 percent goes to oat drink production and the rest becomes feed. In the oatdrink production, the shelled oats are mixed with water, enzymes, rapeseed oil and various additives. Also in this stage a by-product that is used as animal feed is obtained. To make one litre of oat drink 200 gr oats are used, of which half will become animal feed and half end up in the drink, and 20 gr rapeseed of which 12 gr will become animal feed. [7 8]

Eight percent of the arable land in the world is used for soybean production with an annual global harvest of around 250 million tons. Eighty percent of the soybean acreage is found in just three countries: Argentina, Brazil and USA. Trade in soy is by far the most important flow in agricultural trade. The soybean contains around 36 percent protein and one fifth of all protein from all agricultural crops comes from soy. The fat content is 18 percent and soybean oil is the number two oil crop in the world after palm oil. Soy drink is usually made from shelled soybeans going through a number of industrial processes to make them more palatable. Mainly some vegetable oil is added to produce a rounder flavour. Vitamins and calcium are also often added. Between 60 g and 150 g soybeans are used to produce 1 litre of soy drink. Okara, the by-product from soy drink and tofu production, contains one third of the protein and a lot of fibre. Its main use is as animal feed.[10]

Plant-based drinks may sound new and exotic, but it is worth noting that gruel made from a mixture of grain and water or milk has been a very common food for a very long time in Sweden as well. Soy drink has also been a traditional food in East Asia for at least two thousand years.[11] Oat drink in its modern form is still a rather new innovation with commercial production starting in Sweden in the mid-1990's by Ceba foods, now Oatly.[12] The sales of plant-based beverages has grown rapidly in Sweden and according to one assessment they had around 6 percent share of the market 2017. Oat drink is the dominating plant-based milk product in Sweden with at least two thirds of the sales. Soy drink is number two, followed by almond drink.[13] East Asia is still the biggest market for plant-based beverages with more than half of the global consumption.[14 15] Plant-based beverages account for only a few percent of the total share of the global market.[16] Soy drink is the most important product globally.[17]

In Swedish shops, the plant-based alternatives are considerably more expensive than regular dairy milk. The highest price (2018), SEK 40 per litre, was noted for hazelnut drink. The cheapest plant-based beverage, oat drink, cost around SEK 20 per litre compared to regular milk for SEK 12.[18] The reasons for this big difference in price was not examined. ■

The nutritional content

The nutritional content of plant-based milk obviously depends on the use of raw materials, the processing technologies and the common practice of fortifying with vitamins and minerals.

Photo: Providence Doucet, Unsplash

NUTRITIONAL CONTENT OF ONE GLASS OF MILK (2DL) COMPARED TO SOME PLANT-BASED BEVERAGES

	Milk (1.5%)	Oat drink	Almond drink	Soy drink
Energy (kcal)	94	92	48	78
Protein (g)	7	2	1	6
Fat (g)	3	3	2,2	3,6
Calcium (mg)	240	240	240	240
Vitamin D (µg)	2	3	1,5	1,5
Vitamin B12 (µg)	1,2	0,8	0,76	0,76

Sources: Declaration on package of major brands. Note that some of the nutrients are a result of fortification.

The bioavailability of nutrients can differ between different food stuffs and between fortification agents and food. The protein quality of plant proteins is not as good as animal proteins. Milk has a protein digestibility-corrected amino acid score (PDCAAS) of 120, soy 91-93, oats 45-60 and almonds as low as 30.[19] The combination of low protein content and low protein quality of almond and oat drink means that they are not important alternative protein sources when compared with milk.

The nutritional properties of milk and plant-based alternatives are also influenced by production technologies, how cows are raised and how crops and fodder are grown. For instance, the ratio between omega-3 and omega-6 is higher in organic and grass-fed milk than in conventional milk.[20 21] Production technologies also lead to the emergence of new chemical compounds in foods, occasionally unhealthy, e.g. 2-MCPD in vegetable oil, something which has been little researched. ■

Environmental effects

Life cycle assessments are useful for analysing a certain production to identify hot spots of environmental impact in order to direct improvements in a strategic way. They can also be useful to compare two different ways of producing the same products, especially in an industrial context. As agriculture and food system complexity increases the usefulness of life cycle assessments diminishes.

In the production of soy or oat drink the by-products are used mostly to feed animals. For instance, when the rapeseed oil used in the oat drink is produced, sixty percent of the rapeseed seed is a protein-rich feed which is used for dairy production or pig feed. Raising livestock is therefore, in a sense, part of the production of plant-based drink. Along a similar vein, raising calves for slaughter and the slaughter of cows once they no longer produce milk are more or less a pre-condition for the production of milk. While individuals can choose oat drink or milk and not eat meat, at a system level meat consumption, and all its impacts, is embedded in both of them. Dairy cows also eat numerous by-products from the production of plant-based food.

Furthermore, it is difficult, and not even desirable, to isolate products from their context. We do not eat a small number of individual products, but full diets and farming systems don't produce isolated products. Most farms produce several products and there is interaction between the different lines of production as well as between the farms, the food system and society. A change in one factor, such as diets, will trigger cascades of other changes. In addition, there is a big difference when comparing the impact per litre of drink versus its nutritional content. Making statements that one product is superior, or less damaging, based on only life cycle assessments is therefore often misleading.[22] This report therefore combines life cycle assessments, scenario building and system analysis to approach the issues at hand. ■

Land use

In Sweden there is no shortage of agriculture land, to the contrary one third of all cropland has been abandoned in the last 100 years as well as around 4/5 of all semi-natural grasslands. There has been a similar development in most countries of the European Union. From a global perspective, land use is still a relevant parameter. Approximately a quarter of the crop land in Sweden is used for dairy production including calves bred for slaughter.[23] Around 70 percent of the feed is silage and hay from perennial leys. Of the remainder, approximately half is small grains and half concentrates and by-products from the food industry.[24]

CROP LAND USE PER LITRE DRINK AND PER 100 G PROTEIN

Product	m² per litre drink	m² per 100 g protein
Milk, Sweden	1.4–2.4	4.2–7.2
Oat drink, Sweden	0.4–0.5	3.9–7.4
Soy drink, global	0.3–1.7	1.0–5.6

Sources: Milk and oat drink, author's own calculation based on life cycle assessments and statistics from the Swedish Board of Agriculture. Soy drink: Poore, J. and T. Nemecek 2018.[25]

Milk is the beverage with the highest land use measured per litre. Soy drink is clearly the drink with the lowest land use for the production of protein. Calculated in land use per unit protein the difference between milk and oat drink decreases and the further north in Sweden, where the climate is less favourable, the more favourable is milk production. Whole fat milk, which is what is produced by dairy cows, contains three times the energy of oat drink and four times the energy of soy drink, which means that measured per energy unit milk is considerably more efficient. In organic production, yields are much lower than in conventional production while for milk, yields are almost the same as for conventional. This means that the difference in land use between oat drink and milk is smaller in organic production.

The calculation in the table does not include by-products. For example, oats produce more protein per hectare than milk, but oat drink contains only half of that protein. However, the figures for milk also include the production of the meat from calves and replacements. The calculation does not include losses due to low quality. In Sweden, between one fifth and a quarter of the oat acreage will not produce a quality good enough for the production of oat drink, which means that the real land use is some 20 percent higher than calculations based on the volume used in the production.[26] There is no similar quality loss in the dairy production. For soy, the author was not able to find relevant data. In addition to crop land, Swedish dairy utilizes approximately one third of the semi-natural grasslands of Sweden (see more under biodiversity). Those mostly low-producing lands are primarily grazed by dry cows, replacement heifers and steers for slaughter.[27]

Water

Globally, agriculture supposedly uses 70 percent of all freshwater used, and water scarcity and limitations are

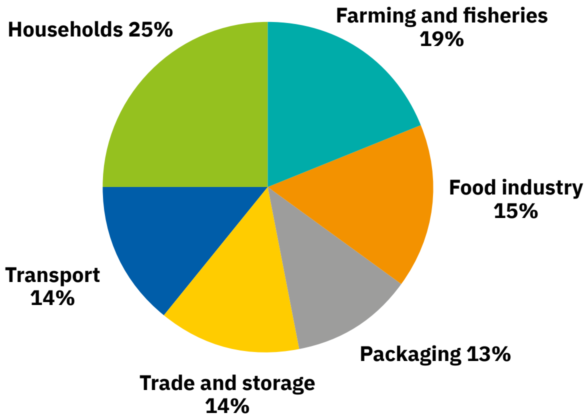
Photo: Jon Flobrant, Unsplash

important for the food system. In Sweden, however, freshwater use by human society is only one percent of the total availability and of this agriculture uses one thirtieth. Water use is therefore not of any major concern. Irrigation is the main use in farming and mostly in vegetables, potatoes, and other high value crops and thus neither for cow feed nor oat production to any extent. Drinking water constitutes the main water usage for dairy cows and the drinking water of animals represents one third of agriculture water use.[28] Water usage in almond production is a well-known problem.[29] Soybeans have relatively low water demands and can be grown without irrigation in most places where they are grown.[30]

Energy

By and large, modern food production is energy inefficient, and the production of milk and plant-based alternatives to milk require more energy than the products deliver. The farm level uses less than 20 percent of the energy spent getting food onto our plates.[31]

ENERGY USE IN THE SWEDISH FOOD CHAIN 2000
(WALGREN & HÖJER 2009)



For milk and its alternatives, energy used in processing, cooling and transportation are important factors. On the farms, energy for fuel and energy embedded in fertilizers are major items. A study of milk production on the farm level in southwest Sweden estimated energy use per litre milk at 2 MJ of fossil energy (fuel and fertilizer) and 0.6 MJ electricity. Energy use in processing was estimated

Photo: Scott Goodwill, Unsplash

at 1 MJ.[32 33 34] The total energy use for oat drink in Sweden was estimated at 7.7-9.2 MJ of primary energy per litre, most for processing, transportation and packaging.[35] One soy drink assessment estimated total energy use until reaching the consumer at 3.4 MJ per litre.[36] As the assumptions and limitations of these analyses vary it is impossible to draw any firm conclusions regarding energy use. Most likely, milk production under Swedish conditions requires more energy at the farm level than the cultivation of annual crops. In a situation where cows are mostly grazing, this would be different. In organic milk production less energy is used, mainly a result of the non-use of artificial fertilizers.[37] In organic oat production less energy is used per area unit, but not necessarily per kg.[38]

Nutrient management, soil health and carbon sequestration

The main problems with eutrophication, nutrient pollution, are caused by linear flows in the farm and food system, exacerbated by global trade. With the large volumes of grain, soymeal and other oilcakes which are traded follow huge flows of nutrients. This depletes soils in exporting countries and leads to an excess of nutrients in importing countries.[39] Sewage and other waste products are rarely recycled to the fields. These are systemic problems and clearly the import of soy for milk production or for soy milk will exacerbate global nutrient imbalances.

Under Swedish conditions the growing of perennial grasses and herbs for silage or hay is most beneficial for soil health. There is no tillage, minimal nutrient run off, low or no use of pesticides, more biodiversity and net carbon sequestration in soils.[40] These perennial leys are the backbone of milk production and the main reason why organic matter content (and thus carbon storage) is considerably higher on dairy farms than on farms with predominantly annual crop production, such as the growing of wheat, rapeseed and oats.[41] Grazing of semi-natural grasslands is also an important land management strategy for soil health, biodiversity and carbon sequestration.[42] There is, however, little research into carbon sequestration in Swedish semi-natural grasslands, but the general view is that they store comparably little carbon as a result of generally low productivity. The production of soybeans, on the other hand, is often associated with monoculture cropping systems and considerable erosion.[43]

Organic production will reduce the problems of eutrophication both at the farm and food system levels and is associated with higher levels of organic matter in soils.[44 45]

Use and diffusion of agrochemicals

Only a few percent of the leys in Sweden are treated with pesticides while around 75 percent of the oat acreages are sprayed with herbicides. In addition, insecticides and fungicides are also used in oat production. The use of pesticides in rapeseed is even higher. It is difficult to compare the use of different agrochemicals as there are many different products used in varying quantities. A calculation based on the USETOX model[46] estimates the toxic load per hectare of rapeseed to more than 40 times the load from ley and the load of grains to 20 times the load from ley.[47] The production of soybeans often involves the use of pesticides such as paraquat, banned within the EU, as well as regular use of glyphosate.

Because dairy cows also eat grain and rapeseed cake or soy meal, the total use of pesticides for the production of 1 l of conventional milk is probably in a similar order of magnitude as for 1 l of oat drink. Dairy production also uses veterinary medicines, such as antibiotics and anti-parasitic compounds, and calves are often treated against diarrhoea. However, the use of antibiotics in Swedish dairy production is very low in an international comparison.[48 49 50]

Pesticides are rarely found in milk in Sweden. Within the EU, 6 percent of all milk samples in 2016 had residues of pesticides, none over the maximum residue limit. Plant-based beverages have not been subject to regular testing. In 2016, 16 percent of all soybean samples in the EU had residues of glyphosate.[51] In 2013, the EU tested oats and found measurable residues in almost half of the samples and 1.3 percent above the maximum residue limit. More than a quarter of the oat samples had residues of several pesticides.[52]

In organic production, pesticides are not used, and veterinary medicines are used sparingly, which means that organic production of either milk or plant-based milk alternatives results in a very low load of toxic substances to the environment and our bodies.

Biodiversity

There are no simple indicators to measure biodiversity in agriculture production. Many impacts on biodiversity from farming occur on a landscape level and are results of the agriculture system rather than the production of a certain crop. Until the middle of the 20th century most Swedish farm were diverse, grew many different crops and had several kinds of animals. Farms and fields were small. Today, farms are much bigger, and fields have been consolidated into larger areas to allow for mechanisation. Diversity has been considerably reduced and most farms have no livestock, while the number of animals has skyrocketed on those that have. Diversity in varieties and breeds has also shrunk. Combined with the use of pesticides and chemical fertilizer these are the main threats to biodiversity.[53]

For biodiversity, under Swedish conditions, the least favourable agriculture production is the conventional growing of annual crops and the most favourable is the grazing of semi-natural grasslands, which are neither fertilized nor cultivated. Such grasslands harbour a stunning number of species and are also among the most threatened landscapes.[54] High-yielding dairy cows also eat annual crops and lactating cows barely graze the semi-natural grasslands, which means that the benefit of milk compared to oat drink for biodiversity is not as great as it could be. Organic production is more favourable for biodiversity than conventional, especially if it is on a smaller scale (however the average organic farm in Sweden is larger than the average conventional farm).[55] Grass-fed organic milk utilizing semi-natural pasture would allow optimal conditions for biodiversity. Soybean production as practiced in major producing countries with large fields of conventional genetically modified soy[56], sometimes on land which recently had high nature values, is clearly very detrimental to biodiversity.

Greenhouse gas emissions

While the calculation of carbon dioxide emissions is quite straight forward and mostly a function of the direct or indirect use of fossil fuels (the other main item is changes in carbon stocks caused by land use changes), the calculation of emissions of nitrous oxide and methane is not simple. The constants used for expressing methane as carbon dioxide equivalents (CO2e) cannot capture the inherent difference between carbon dioxide and methane. While methane has a much stronger greenhouse effect it remains a much shorter time in the atmosphere, in average just over ten years. Constant methane emissions, therefore, do not lead to continued warming, while constant carbon dioxide emissions accumulate over centuries. This has huge implications for dairy production as methane constitutes most of the greenhouse gas emissions as they are generally counted.[57 58 59]

For nitrous oxide, the complication is rather the uncertainties and variability in the emissions themselves. Life cycle assessments are hardly ever based on actual measurements of emissions but use national emission factors assigning a certain load proportional to the use of synthetic fertilizers and manure.[60 61] When New Zealand adjusted their national emission factors for nitrous oxide and based them on actual measurements instead of IPCC standard factors, the total greenhouse gas emissions from the dairy sector shrank by 15 percent.[62] Other research show that organic production and other production methods with low nitrogen input are systematically misrepresented in life cycle assessments.[63]

Photo: Katie Moum, Unsplash

In Sweden, drained organogenic soils represent the main source of the farm sector's greenhouse gas emissions.[64] In a similar way, deforestation of rainforest caused by soybean cultivation is a major source of greenhouse gas emission. In most cases this is not included in life cycle assessments.

With reservation for the shortcomings in methodology as well as for differences in assumptions and system boundaries, 1 litre of milk in Sweden results in greenhouse gas emissions of around 1 kg CO2e per litre at the farm level[65] and 1.4 kg at the consumer level, according to several estimates.[66] The only available life cycle assessment for oat drink calculates the emissions at the consumer level at between 0.4 and 0.5 CO2e[67] and a global meta-analysis set average emissions from soy drink to 1 kg CO2e per litre, with a variation from 0.3 to >2 CO2e.[68] Similar to the land use discussion, the results depend on the functional unit chosen. If protein supply was chosen as the functional unit, milk would have more or less the same emissions as oat or soy drink. Adding more nutritional parameters could tilt the comparison in favour of milk.[69] Adding carbon sequestration in soils to the assessment would also improve the results for milk (see above).

Notably, Sweden has an energy system which has largely phased out fossil fuels (it is based on hydroelectricity, biomass, nuclear and wind). This influences comparisons between production taking place in other countries and in Sweden. Processing soy drink would, therefore, cause considerably less emissions if it took place in Sweden.

Life cycle analyses provide no conclusive results regarding greenhouse gas emissions from organic and conventional production of milk or plant-based alternatives.[70 71]

The bigger picture

Instead of looking into side-by-side comparisons for impact categories of not so easily comparable products, one can also analyse the production from a food system or farm perspective. Scenarios from Sweden and the Nordic countries based on organic production, the efficient use of by-products from the food system as well as the full utilization of semi-natural grasslands show that a rather high milk consumption can be sustainable.[72 73 74]

A calculation of the effect of a total replacement of dairy production with oat drink[75] shows that 560,000 ton of oats and 22,000 tons of rapeseed would be needed to replace 2.8 million tons of milk. Taking into account the need for seed production and quality declassification (20%) 190,000 hectares arable land would be needed, compared to 450,000 hectares used for dairy production. To supply the same amount of protein and energy, however, there is a need for another 200,000 hectares of yellow peas and rapeseed. The total area needed would thus be fairly similar for the two alternatives.
In a conventional farming system, the oat drink scenario would need less land (86%) but in an organic system the difference disappears.

In the oat drink scenario, huge quantities of animal feed would also be produced. And obviously that will also result in food for people, in a similar way that the milk scenario would also produce meat. More important than the effects on land use would be the impact on biodiversity and on farming in less favoured areas. In less favoured areas, dairy production or the rearing of cattle originating from dairy farms are almost the only kind of production that is somewhat competitive. Maintaining farming in those areas is of critical importance both for biodiversity and rural livelihoods. More semi-natural grasslands would be lost in an oat drink scenario. The cropping system would also lose much of the leys which today are regulating weeds and disease, binding carbon and building soil health. For the farm sector as a whole, Photo: Rawpixel, Unsplash

there would be a huge loss of income. In 2016 prices, gross income from dairy farming of SEK 9 billion, and half of the beef production, worth SEK 6 billion, would vanish and with it some 15 000 jobs. The increased production of oats, peas and rapeseed would employ just around 1,000 persons and with a corresponding decrease in revenues.

A soy drink scenario would obviously be even more dramatic as it would mean massive abandonment of farmland in Sweden as well as an increased reliance on imports. It is possible to grow soybeans in the most favourable locations in Sweden, but it is certainly not competitive.[76] ■

Conclusions

This analysis does not support the notion that the individual choice between oat drink, soy drink and milk is a choice of critical importance for the environment. Individuals can have different preferences regarding taste, ethics etc. And the same person can prefer an oat creamer in their coffee while eating oatmeal porridge with milk. From a nutritional perspective, most people in wealthy countries do not have to drink milk or its replacement, they can just as well drink water. And the environmental and social effects of coffee production is probably more important than whether the coffee is mixed with milk, cream, or alternative creamers. One cannot make conclusive statements that one product is superior the other. Each product has its strengths and weaknesses, but how they are produced is mainly of greater significance.

From a food systems perspective there are also no reasons to position oat drink and milk as mutually exclusive alternatives. Oats and milk can be, and often are, produced on the same farm. Dairy cows or their offspring can eat oats which is not good enough for the industry, lie on oat straw bedding and eat leftovers from the oat drink production. The oats can be fertilized with cow manure and benefit from a crop rotation including leys for cattle feed. ■

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Milk and plant-based alternatives – an environmental assessment

This brief compares the environmental effects of dairy products and plant-based alternatives, mainly oats and soy, to dairy under Swedish conditions. It also discusses, where relevant, the differences between organic and conventional production.

The brief is a summary of a report titled *Mjölkprodukter och vegetabiliska alternativ till mjölkprodukter – miljö, klimat och hälsa*, commissioned by the MatLust project, in the municipality of Södertälje, Sweden. The report as well as this brief are written by **Gunnar Rundgren**, an internationally renowned agricultural consultant. Gunnar was chairman of IFOAM (International Federation of Organic Agriculture Movements) in 2000–2005 and is frequently hired as expert by organisations such as UNEP, UNCTAD, FAO, The World Bank and the Swedish International Development Cooperation Agency, Sida.

MatLust is an EU-funded project. The goal is to develop a sustainable and profitable food industry in the Stockholm region. MatLust offers development programmes, testbeds, networks and other forms of support for small and medium sized food companies. Södertälje Municipality leads the project with Södertälje Science Park, KTH Royal Institute of Technology in Stockholm, and Stockholm Resilience Centre at Stockholm University as collaborative partners.

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