FACT SHEET

Forschungsinstitut für biologischen Landbau
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Research Institute of Organic Agriculture

EXCELLENCE FOR SUSTAINABILITY

Organic Farming and Sustainability

Life cycle assessments of organic foods

Life cycle assessments (LCAs) have become an established tool for the assessment of ecological sustainability in the farming and food sector. They help to improve production, provide a basis for political decision-making, and deliver consumer information. Life cycle assessments are also used to compare agricultural production systems.
Contrary to expectations, in product-based comparisons, foods produced in extensive production systems such as organic farming are often shown to have a lower eco-efficiency than foods from more intensive production systems. However, eco-efficiency alone is not a sufficient indicator of whether an agricultural product was produced in an environmentally sound manner. For a comprehensive environmental assessment of agricultural products, site-specific production factors must be integrated more firmly into life cycle assessments. To this end, a wider perspective needs to be taken.

Life cycle assessment – a tool designed to estimate environmental relevance

Life cycle assessments were originally developed in order to assess the environmental impacts of industrial processes and products (Fig. 1, p. 2). They are now increasingly used to assess agricultural processes and products.

A life cycle assessment (LCA) allows for the quantification of a product's impact on the environment over its entire life cycle. It takes account of environmental impacts caused during raw material extraction, production, utilisation and disposal (or recycling) including all transport processes. Moreover, life cycle assessments allow for comparisons to be made between the environmental impacts of different products that provide the same function. They are compared upon a common benchmark (the functional unit). To give an example from the food sector, this makes it possible, for example, to compare the environmental impact of an organic tomato with that of a conventionally produced tomato.

Impacts of farming on the environment are many and varied. Even when using soil-conserving production techniques such as direct seeding with disc coulters or low-loss application techniques such as drag-hose systems, adverse environmental impacts are unavoidable.

It is standard practice for LCAs to quantify a broad range of environmental impacts, such as global warming, potential eutrophication of soils and water bodies, soil acidification, human toxicity and eco-toxicity, ozone (layer) depletion and photochemical ozone formation (summer smog) (Fig. 2). They also account for energy and resource consumption (land, water, nutrients etc.) throughout the entire production process. These environmental impact categories are either stated individually as numeric values or are aggregated into a single value as an expression of the product's overall environmental impact. The aggregation of individual environmental impact categories into a single value requires that the individual parameters are weighted, and thus contains a value judgement.

Measured inputs, estimated environmental impacts

In order to calculate environmental impacts using LCA, data on **mass and energy flows** are needed, i. e. mass and energy that enter a process (inputs) and leave the process again in the form of outputs. Inputs relevant for the environmental assessment of agricultural products include, for example, seeds, fertilisers and pesticides as well as machinery use including diesel fuel. The yields obtained on agricultural land, such as cereals or straw, constitute the output. Starting off with substance and energy flows on the input side, an LCA uses models to estimate, for example, the amount of greenhouse gas emissions arising in a process, or the toxic effect resulting from a process.

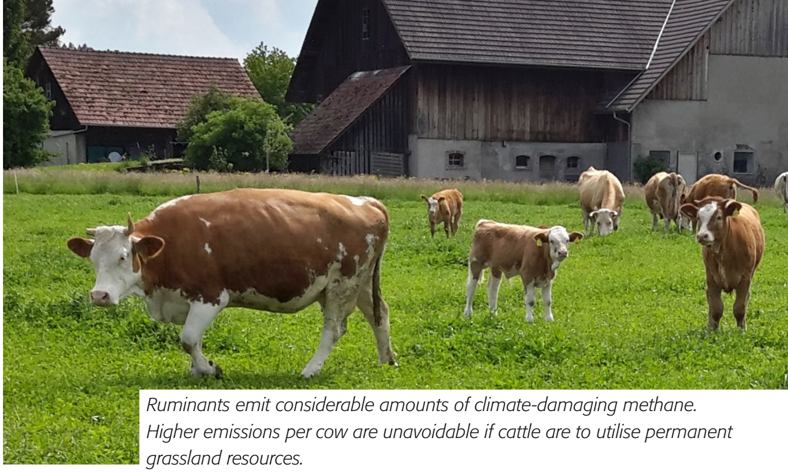
LCAs depend on the use of **models** to assess impacts because it is impossible, at reasonable expenditure of time and money, to measure the environmental impact along the entire life cycle of a product. However, models offer only an incomplete reflection of reality and must inevitably rely on simplifications and assumptions. When using models in LCA, and especially when it comes to agricultural products and processes, it is crucial that they allow for sufficient differentiation between the production systems that are to be evaluated. Otherwise it will not be possible to make meaningful comparisons between products from different production systems and to draw purposeful conclusions on the environmental impacts of different systems.

Product-based environmental impact as a measure of eco-efficiency

In LCA, environmental impact is often referenced to product quantity as the functional unit; this is also true for agricultural products. The environmental impact resulting from agricultural land use is therefore divided by the yield obtained per unit area.

Fig. 1: In contrast to industrial processes, agricultural production is subject to complex interactions with the environment. It is a great challenge to capture this complexity in life cycle assessments.

Organic farming does not refrain entirely from the use of pesticides. However, the natural substances used are generally less environmentally harmful than synthetic pesticides.



Ruminants emit considerable amounts of climate-damaging methane. Higher emissions per cow are unavoidable if cattle are to utilise permanent grassland resources.

This reference to products is an expression of the environmental impact resulting from the production of a certain quantity of product and is thus a measure of eco-efficiency. Where a comparison is made between the same products produced in different agricultural production systems, the intention is to identify the production system which can produce the same product quantity with the lowest level of environmental impacts. Or in other words: The aim is to find the production system characterised by the most optimal ratio between environmental impacts caused by the use of inputs (fertilisers, pesticides, machinery) and the obtained output (yield).

Overall assessment yields no clear distinctions

Comparative LCAs of organic and conventional foods are often used to make an overall assessment of the environmental impact of production systems as a whole. If an overall view is taken of all assessable environmental impact categories together, comparative LCA of organically and conventionally produced foods with reference to the product (e.g. per litre of milk or kilogram of bread) often do not yield conclusive results as to the systems' benefits and disadvantages for the environment [1].

Assessment by individual impact categories shows greater differences

There are, in part, considerable differences in the performance of organic and conventional products if one considers individual impact categories. For some impact categories, such as global warming potential, eutrophication of watercourses and soil acidification, product-based LCAs often ascribe greater environmental impacts to organic foods than to their conventional counterparts [1]. However, in almost all cases organic foods have better scores for human toxicity and eco-toxicity as well as energy consumption than conventional foods [1] due to the fact that synthetic pesticides and mineral fertilisers are not used in organic farming. But there are also foods where organic production yields better, similar or worse scores for the same impact category compared to conventional production (see the example of the milk carbon footprint on p. 5).

Studies that often solely assess global warming potential describe organic farming as inefficient with reference to its environmental impact (e.g. Vogel, 2015 [2]). However, systems comparisons based on human toxicity and eco-toxicity would come to the conclusion that organic farming is more environ-

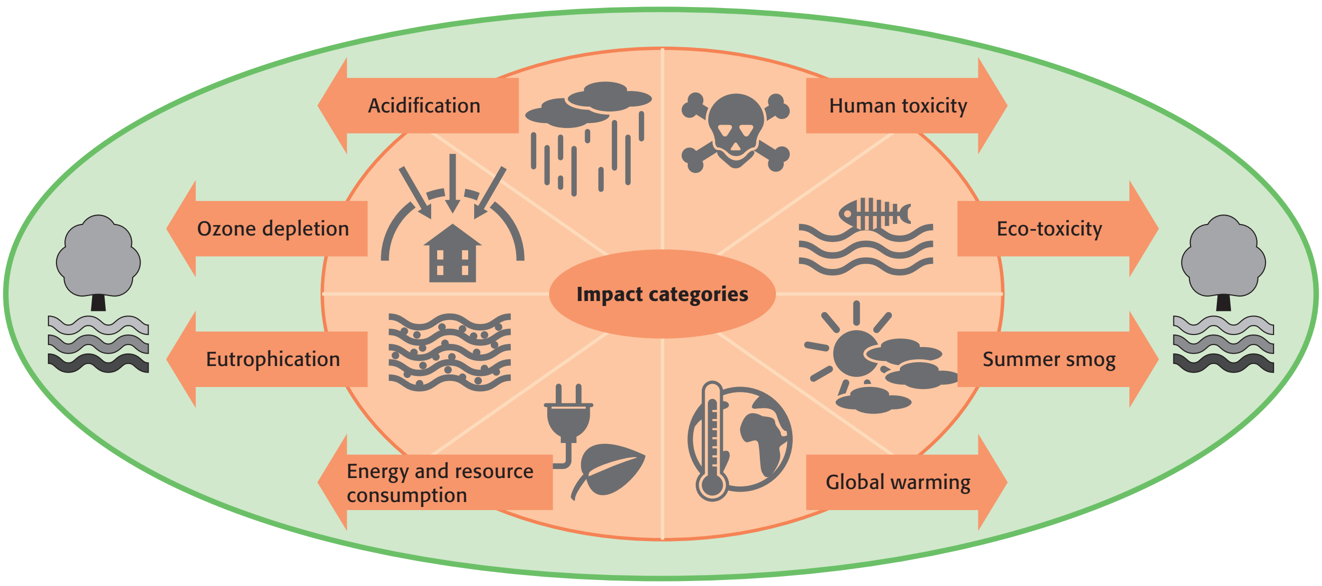


Fig. 2: Impact categories denote environmental issues that, as part of the LCA, are quantified using impact indicators. The environmental issues given above are those usually considered in LCAs of agricultural products.

In life cycle assessments, higher yields generally equate to higher eco-efficiency. Yields in organic arable farming are 20 to 25% lower on average than their conventional counterparts; these lower yields can result in a lower eco-efficiency score as part of the environmental assessment.

mentally sound. The ambiguous picture painted by product-based LCAs of organic foods continues to clash with farm-based assessments as to the ecological sustainability of organic farming that have shown clear benefits of organic production [3] [4]. At the same time, a range of studies have clearly shown that intensive farming – and conventional production largely falls into that category (see also Box below) – causes widespread environmental damage such as soil degradation, water pollution and loss of biodiversity [5] [6] [7].

There is a variety of potential reasons for this ambiguous picture, i.e. the sometimes better and sometimes worse performance of organic agriculture in product-based LCA:

1. The eco-efficiency of organic food is indeed better, similar or indeed worse than that of conventional products.
2. Emissions models (especially those for reactive nitrogen emissions such as ammonia, nitrate and nitrous oxide) do not sufficiently differentiate production systems, resulting in an artificially lowered eco-efficiency of organic products.
3. The product-based perspective focuses in an imbalanced manner on eco-efficiency without taking into consideration whether a production system reaches or even exceeds the local environment's carrying capacity. If this approach is taken, the eco-efficiency score does not sufficiently answer the question as to whether a specific production intensity is or is not environmentally sound. As part of a product-based perspective, it does not allow for a conclusive assessment of the environmental benefits and disadvantages of an agricultural production system.

The three potential explanations offered here can be of significance to environmental assessments of agricultural products and the conclusions drawn from such assessments. Therefore, we will discuss them in detail below.

Intensive vs. extensive farming: What level of intensity is better for the environment?

Organic farms primarily rely on their holding's own resources (livestock farm waste, feedstuffs) for their production of agricultural products and forego mineral fertilisers and synthetic pesticides. Given the usually much lower proportion of brought-in farm inputs, organic production is more extensive overall than conventional production. Accordingly, input quantities in terms of fertilisers, pesticides, livestock densities, machinery use and/or usage frequencies (e.g. number of grassland cuts per year) per unit area are generally lower in organic production. Environmental impacts per unit area are lower as a result. For example, nitrogen surpluses are normally lower on organic farms than on conventional holdings, with lower corresponding emissions in terms of reactive nitrogen compounds (ammonia, nitrous oxide and nitrate). This is the reason why organic farming is considered to be a potential measure to reduce nitrogen surpluses [8].

However, the lower production intensity per unit area of organic farming mostly entails lower yields per unit area. Organic farms, therefore, need more land than conventional farms to produce the same quantity of a given product.

The lower quantities of fertilisers applied per hectare and the non-use of synthetic pesticides in more extensive agricultural production systems such as organic farming often necessitate higher machinery use for mechanical weed control.

With regard to eco-efficiency, one would expect, for a given plot of land, the ratio of environmental impact to yield to be roughly similar for organic and conventional production systems: Lower inputs in organic farming result in lower environmental impacts per unit area. If one divides the lower environmental impact per unit area by lower yields per unit area, the result should generally indicate a similarly high eco-efficiency as is found in more intensive systems which generally produce higher yields. However, the latter's environmental impact per unit area is also higher due to its higher input use.

The modelling of environmentally relevant nitrogen emissions from fertiliser applications is very challenging, especially if a differentiation is to be made between the environmental impacts of organic and mineral fertilisers respectively.

Differences between products, production systems and impact categories

The following example of greenhouse gas emissions of organic and conventional dairy products demonstrates the difficulties faced in assessing the eco-efficiency of foods produced in different production systems. Figure 3 shows the greenhouse gas emissions per kilogram of milk produced by cows with different levels of annual milk yields as published in 11 comparative LCAs including a total of 13 paired comparisons [1]. The milk production studies considered here include cows with annual milk yields of between 3,000 and 10,000 litres.

Milk yields – a measure of production intensity – is lower on average on organic farms (red dots) than on conventional farms (blue dots). Eco-efficiency can vary widely, independent of milk yield class and production system. There are organic production systems with low greenhouse grass emissions per kilogram of milk and low annual milk yields; there are also conventional production systems with high milk yields and high (or indeed low) greenhouse gas emissions per kilogram of milk. The most eco-efficient milk in terms of global warming potential was produced on an organic farm. On average, across the studies, the global warming potential of organic milk was roughly equal to that of conventional milk (1.04 kg CO_2eq. / kg organic milk compared to 1.09 kg CO_2eq. / kg conventional milk). This example confirms the expectation that the eco-efficiency of extensive and intensive production systems is roughly similar (see also the Box on p. 4).

Examples in which the eco-efficiency in terms of global warming potential is significantly lower in extensive production systems than in intensive systems can be found, for example, in beef production. Figure 4 shows the carbon footprint per kilogram of finished weight (the animals' life weight at the point of slaughter) as calculated for different finishing systems used in Switzerland: 'Bio Weide-Beef' is an organic grassland-based production system where the animals are fed concentrate feeds only towards the end of the finishing period, if at all. 'Terra Suisse' and 'QM Schweizerfleisch' are two conventional concentrate-based indoor housing systems. The 'Terra Suisse' system differs from the 'QM Schweizerfleisch' system in that it has higher animal welfare requirements and a somewhat lower animal density.

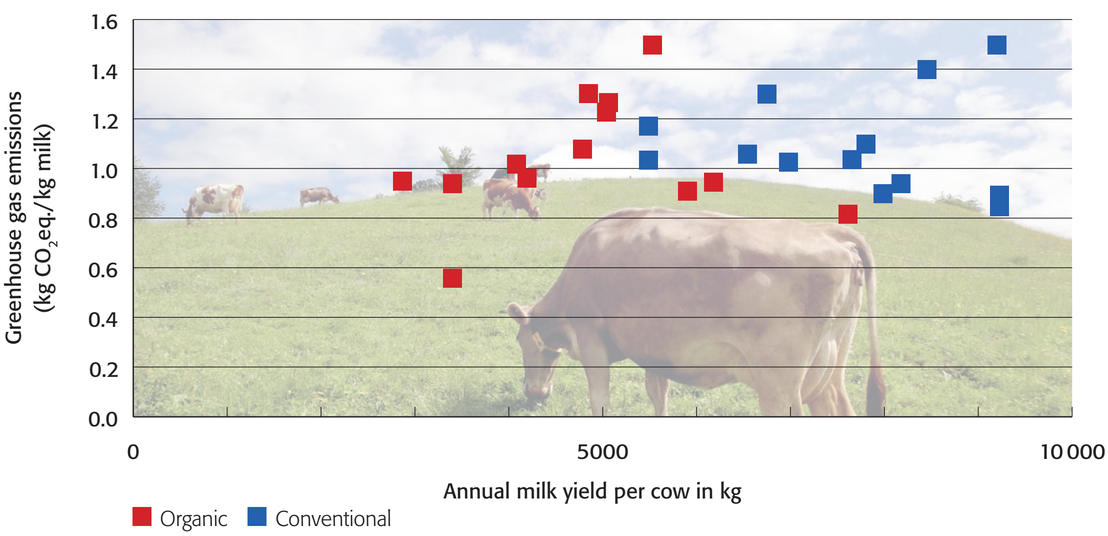


Fig. 3: Juxtaposition of greenhouse gas emissions per kg of milk and annual milk yield per cow based on the analysis by Meier et al. (2015) of comparative studies of organic and conventional milk respectively (13 paired comparisons from 11 LCA studies).

Concentrate-based intensive beef production (left) is highly eco-efficient. However, the imported nutrients from bought-in concentrate feeds can locally result in eutrophication of soils, groundwater and surface water and can cause a loss of biodiversity. In contrast, extensive organic pasture-based beef production utilises local resources optimally and meets high animal welfare standards, but because it takes longer for the animal to reach its finishing weight this type of production results in higher methane emissions than the intensive system.

Both in the more extensive, grassland-based production system and in the two more intensive, concentrate-based systems the animals reach a finished weight of approximately 550 kg. While the animals in the more intensive concentrate-based systems are finished within 13 to 15 months as a result of the use of concentrate feeds, they only reach their finished weight at 20 to 26 months in the grassland-based organic system. Given that the cattle in the grassland-based system take up to twice as long to reach their finished weight, they also emit more methane accordingly. This is the reason for the difference in the carbon footprint (Fig. 4) and results in a lower eco-efficiency score with regard to greenhouse gas emissions.

Inaccurate differentiation of production systems in emissions models

It is notable that in numerous LCA studies on different product categories, organic foods – with few exceptions – score worse than conventional foods in product-based environmental assessments with regard to carbon footprint, eutrophication of watercourses, and soil acidification [1]. Reactive nitrogen emissions such as ammonia, nitrate, nitrogen oxides and nitrous oxide are responsible for the environmental impacts of the impact categories listed. The emissions primarily result from surplus nitrogen in the agricultural production system necessary to achieve stable yields.

Of all the agricultural nitrogen emissions, **nitrous oxide** has the greatest significance for climate change. It is generated by bacterial processes in soils, a process that is amplified by fertiliser applications. Eutrophication of watercourses with nitrogen is primarily a result of the **loss of nitrates** from fertilisers that leach into watercourses. **Ammonia** is a cause of both eutrophication and soil acidification. Agricultural ammonia emissions result primarily from the use of organic fertilisers and from livestock production. **Nitrogen oxides** are generated by bacterial processes in soils or are produced during fuel combustion in farm machinery. A proportion of the nitrogen losses in the form of nitrates, ammonia and nitrogen oxides are converted into nitrous oxide which then escapes into the atmosphere, which means that the former substances also contribute indirectly to global warming.

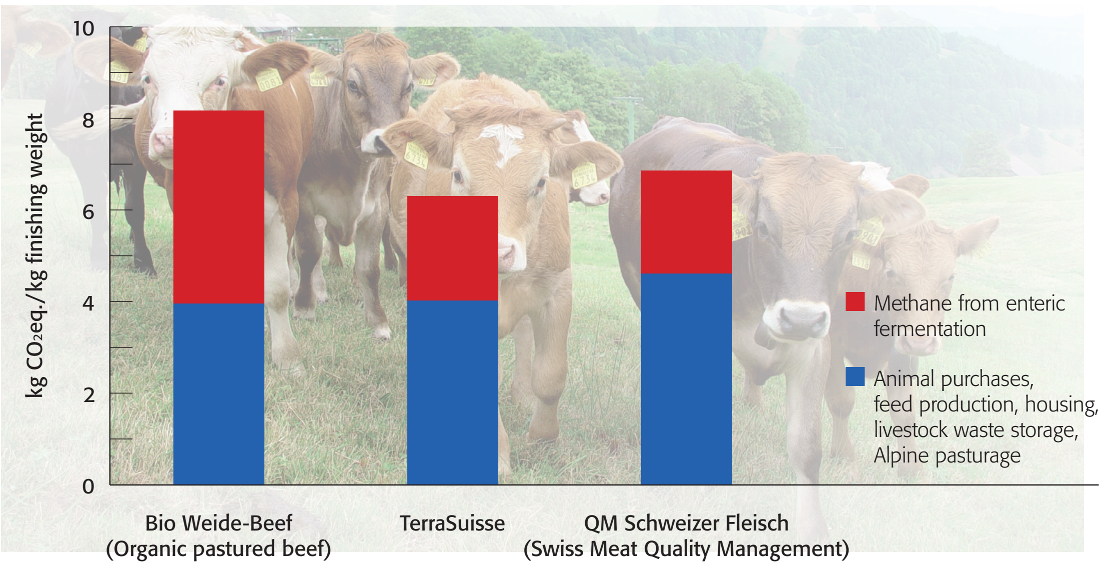


Fig. 4: Average greenhouse gas emissions per kg of finished weight of beef produced in different systems (figure adapted after Meier et al., 2014 [9]).


The emissions models used in the LCA inventories examined predict overly high nitrogen losses for organic cereal production.

In LCA inventories, nitrous oxide, nitrate and ammonia emissions are normally calculated using different, mutually independent models. The different emissions are estimated primarily based on nitrogen inputs from fertiliser use. As a result of this independent modelling, the amount of nitrogen included in the emissions calculations often does not equate the actual amount of surplus nitrogen in an agricultural production system that may be lost to the environment in the form of emissions.

Table 1 shows for four agricultural crops, i. e. wheat, barley, soya and potatoes, how strongly the nitrogen quantity calculated as part of the emissions modelling (nitrate, nitrous oxide, ammonia and nitrogen oxides) can deviate from the surplus nitrogen in the production system; it also relates these quantities to the amount of nitrogen added into the crop production system by way of fertilisers. The nitrogen quantities calculated as part of the emissions modelling and the nitrogen fertiliser inputs were taken from relevant LCA inventories in the ecoinvent database [1] (V. 3) [10]. The surplus quantities shown in the table are primarily derived from the quantity of nitrogen contained in the crop plant biomass. Plant biomass can be used to estimate the amount of nitrogen that must have been available to the plant in order to achieve the stated yield. The surplus is calculated by subtracting the nitrogen contained in the plant biomass from the nitrogen available from fertilisers, soil and aerial deposition. As the emissions models also include long-term nitrogen emissions, any comparison must add to the calculated nitrogen surplus the quantity of nitrogen that may be lost in the long-term in the form of emissions from nitrogen contained in crop residues and from the soil nitrogen pool generated by organic fertiliser applications. The amount of surplus nitrogen required to build up plant biomass and the quantity of nitrogen from subsequent long-term emissions are of course only estimates and therefore subject to uncertainties. Nonetheless, it is possible to demonstrate the degree to which the nitrogen quantities calculated by emissions modelling deviate from the surplus quantities.

With the exception of conventional wheat, the relative deviations between the nitrogen quantities calculated by emissions modelling in the inventories and the estimated surplus quantities shown in

[1] The ecoinvent database provides inventory data for thousands of products that can be used for the purposes of life cycle assessments. Among many other data they also include data on a multitude of agricultural processes and products. www.ecoinvent.org

Table 1: Relative deviation of the nitrogen quantity indicated by emissions calculations based on the LCA inventory data (ecoinvent 3; Wernet et al., 2016[10]) from the surplus nitrogen by crop production system. [2]

	Wheat Org.	Wheat Conv.	Barley Org.	Barley Conv.	Soya Org.	Soya Conv.	Potato Org.	Potato Conv.
Nitrogen inputs from fertiliser based on ecoinvent 3 inventory (kg N / ha)	114	146	93	126	20	27	83	118
Quantity of nitrogen from emissions modelling in ecoinvent 3 inventories (kg N / ha)	111	78	98	81	26	28	46	52
Calculated surplus based on nitrogen uptake of crop plants (kg N / ha)	72	82	58	68	75	79	120	134
Percentage deviation of emissions modelling (surplus based on nitrogen uptake = 100 % baseline) [2]	54 %	–5 %	69 %	19 %	–65 %	–65 %	–62 %	–61 %

[2] Positive deviation: nitrogen quantities based on emissions calculations are higher than the nitrogen surplus present in the crop production system; Negative deviation: nitrogen quantities based on emissions calculations are lower than the nitrogen surplus present in the crop production system.

The nitrogen emissions stated for potato and soybean crops in the LCA inventories examined are strongly underestimated – with minor differences between the organic and conventional cropping system.

Table 1 are considerable. Moreover, the deviations between the different crops and production systems (organic/conventional) are highly heterogeneous. For soya and potatoes, the emissions models used in the LCA inventories considered here hugely underestimate the nitrogen emissions, while the difference between the organic and conventional production system for these crops is minor. For the winter wheat and winter barley inventories, the LCA inventories' nitrogen models show overly high values (exception: conventional wheat). At the same time, the differences between organic and conventional agriculture within individual cereal species are considerable. The emissions models in the LCA inventories considered here use much higher emissions values for organic cereals.

One of the main reasons for the heterogeneous picture given in Table 1 is likely to be the different ways in which organic fertiliser (slurry and farmyard manure) and mineral fertiliser are given consideration in the emissions models, and first and foremost in nitrate modelling. For soya and potatoes, the inventories considered here assume similar amounts of nitrogen inputs from organic fertilisers for both organic and conventional production, which is why there are no significant differences between the cropping systems. In the cereals inventory, however, only a small amount of organic fertiliser is ascribed to the conventional system with the bulk input considered to be mineral fertiliser.

Moreover, looking at the absolute nitrogen quantities given in the inventories as based on the emissions models, it is notable that the nitrogen losses per hectare for organic wheat and organic barley are significantly higher, and for organic soya and organic potatoes only slightly lower than their conventional counterparts, despite the fact that nitrogen inputs per hectare from fertiliser are lower in organic systems than in conventional systems. This is likely due to the fact that the models used for the inventories ascribe significantly higher losses to organic fertilisers than to mineral fertilisers. The amount of nitrogen lost by way of emissions is given as 111 kg/ha/year for organic wheat and 98 kg/ha/year for organic barley. On the input side, the inventories show nitrogen inputs from fertiliser of 114 kg/ha and 93 kg/ha for organic wheat and barley respectively. This would indicate that practically the entire nitrogen input from fertiliser to organic wheat and barley crops is lost as emissions. However, that is unrealistic as it would then be impossible to achieve the yields given in the inventory.

A conclusive assessment of the differences observed would necessitate a deeper analysis. Nonetheless, it is possible to draw the following conclusions:

1. Modelling of reliable nitrogen emissions values by means of simple models as used in the LCA inventories of agricultural products has limitations.
2. It is difficult to clearly differentiate between different agricultural production systems such as organic and conventional systems in terms of their global warming potential, eutrophication and soil acidification on the basis of the currently widely applied nitrogen emissions models within LCA inventories.

The product-based perspective's one-sided focus on eco-efficiency

Product-based LCA (Fig. 5) focuses on eco-efficiency and thus evaluates a very specific component of ecological sustainability. Its reference to products means that it looks at the degree to which the environment is burdened for the purposes of producing a specific product quantity. This perspective aims primarily at identifying the production system that causes the lowest level of environmental impacts for the purposes of producing a unit of product, i.e. the production system characterised by the most optimal ratio between product output and environmental impact.

In principle, the optimal ratio between product output and environmental impact in the production of agricultural products can be achieved in both intensive and extensive agricultural systems (see the example of milk production). However, in the comparative life cycle assessment of intensive, concentrate-based and more extensive, grassland-based beef production systems (all conventional) conducted by Wolff et al. [11], the intensive production systems were shown to have the highest eco-efficiency scores for most of the impact categories. A similar picture emerged from the example of the carbon footprint in beef production given earlier (Fig. 4, p. 6). Given these results, it might appear

Intensive farming can result in very high local impacts from nitrates, pesticides and erosion. Under certain circumstances the natural carrying capacities are exceeded locally.

that beef produced in intensive, concentrate-based production systems is more environmentally sound.

However, an increasing number of studies has shown that it is these intensive livestock production systems in particular that are the main cause of the high levels of surplus nitrogen and the resultant environmental problems in Switzerland, Europe and worldwide [8] [12] [13]]. Given that the production of agricultural commodities takes place over large areas, the intensity of agricultural production significantly determines agriculture's environmental impacts. A low environmental impact per kilogram of product therefore does not a priori imply that the product was indeed produced in an environmentally sound manner.

Given the intensity of the production system, the environmental impact at the production site in particular can be very high. High levels of environmental impacts can be found, in particular, in regions characterised by intensive farming. For example, in regions with intensive livestock production nitrate threshold values in groundwater are often exceeded. Moreover, increasing levels of eutrophication have been found in semi-natural habitats. Watercourses contain pesticide residues, and high levels of greenhouse gases are being emitted per unit area.

Environmental impacts from overly intensive agriculture can be so high as to exceed the environment's natural carrying capacities and may render impossible long-term sustainable agricultural production at the site in question. If the assessment of the ecological sustainability of agricultural products is reduced to the environmental impact per unit of product, the local environmental impact or an overall exceedance of natural capacities will therefore not become visible. Where product-based LCAs of foods from intensive agriculture come to the conclusion that these are highly eco-efficient, they neglect to state that the intensive production may result in a long-term loss of soil fertility as a result of loss of soil carbon or as a result of salination due to intensive irrigation. An exclusively product-based environmental assessment is therefore not sufficiently comprehensive and does not allow for a final verdict as to the ecological sustainability of agricultural products.

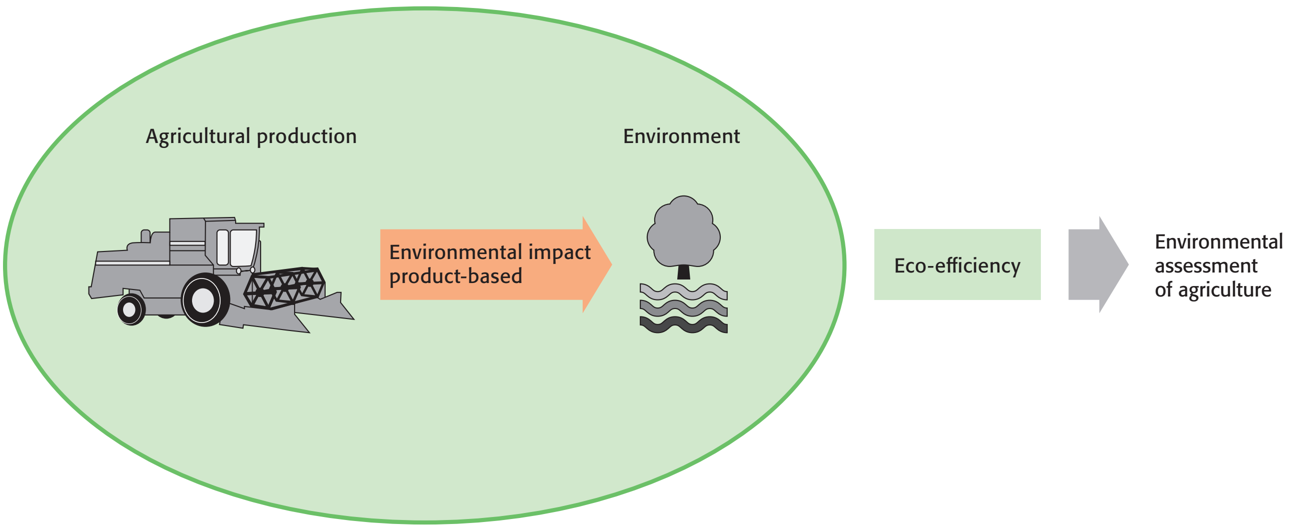


Fig. 5: The concept of product-based life cycle assessment: The environmental impact of agricultural production is referenced to the quantity of product produced per unit area. The local context of the production site is not taken into consideration.

In some cases, intensive agricultural production (left) visibly exceeds the site's natural carrying capacity. Site-appropriate agricultural production, in contrast, is guided by the location's ecological carrying capacity and the locally available resources.

Consideration of natural local carrying capacities and resource constraints

In addition to a product's eco-efficiency, as a minimum an assessment would need to be made as to whether its production at the site in question is compatible with local carrying capacities and resource constraints or whether the environmental impact at the site is excessive (Fig. 6). Local carrying capacities and resource constraints, which are a function of regional locational factors such as ecosystem sensitivity, water reserves, soil characteristics and climatic conditions, are still not given sufficient consideration in LCAs to date. However, regional locational factors are crucial in the context of sustainability assessments of agricultural products, as they determine the level of intensity of production that a specific site can sustainably maintain.

On marginal alpine pastures, for example, beef production in suckler cow herds is indeed a site-appropriate form of agricultural production that allows for sustainable utilisation of alpine permanent grassland. In terms of its eco-efficiency with regard to several environmental impact categories, a kilogram of beef from an Alpine suckler herd can certainly not measure up to beef from a concentrate-based housed herd in which surplus dairy calves are normally fattened for beef [9] [14]. In a suckler herd, the beef is ascribed not only the calf's but also its mother's emissions. Yet it would not be expedient to advocate concentrate-based beef production in Alpine regions on account of its greater eco-efficiency – due to locational factors, that cannot constitute a sustainable production.

A stronger regionalisation in LCAs of agricultural products would allow for the integration of local site factors such as ecosystem sensitivity or the presence of groundwater reserves. Based on locational factors, local carrying capacities could be defined which land uses should not exceed. It would then be possible to identify within these carrying capacities the production system with the highest eco-efficiency. An assessment perspective expanded in this manner would also make it easier to integrate additional impact categories such as biodiversity or soil quality.

Impacts on biodiversity and soil quality are strongly dependent on regional locational factors and can in reality only be evaluated purposefully

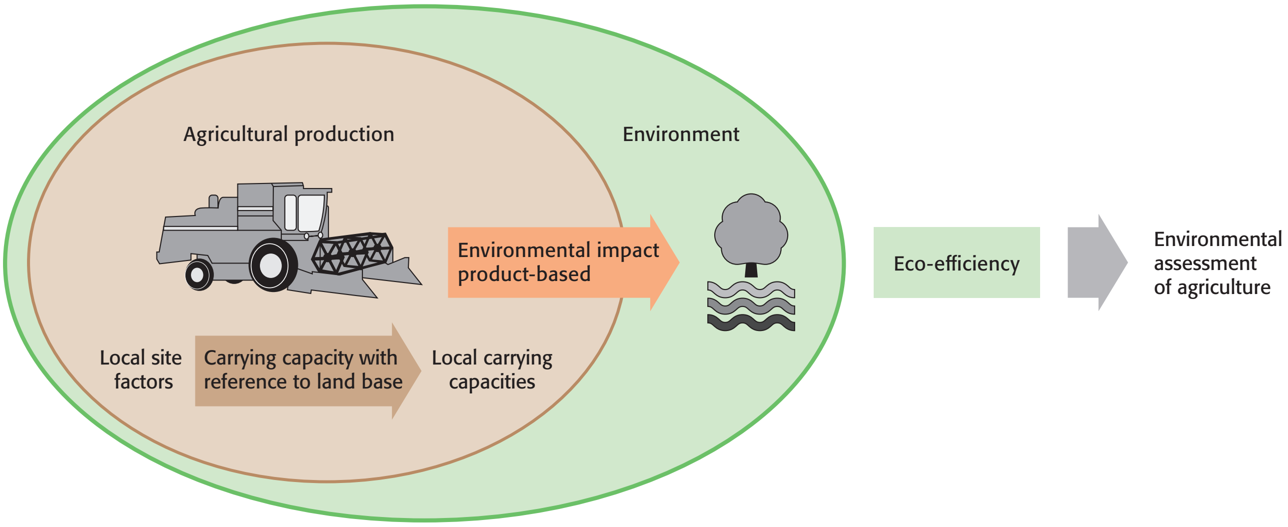


Fig. 6: *Assessment of the ecological sustainability of agricultural products, taking account of local natural carrying capacities and resource constraints. A site's carrying capacity is determined with reference to the land base and expressed, for example, in terms of maximum nitrogen inputs per hectare. As part of the product-based environmental assessment a determination is made as to whether production takes place within these limits.*

Biodiversity and soil quality in particular are environmental factors which typically have a local carrying capacity. They should be assessed as part of LCAs, taking into consideration the local site conditions.

if a regional view is taken. An additional advantage of stronger regionalisation in environmental assessment would be the fact that trade-offs between agricultural production and other objectives such as the maintenance of semi-natural habitats could be made more transparent.

Conclusions on the use of LCA for the assessment of environmental impacts of agricultural products

There is an urgent need for agricultural production systems that are more environmentally sustainable while producing sufficient quantities of food. The answer to the question as to which of the production systems are more environmentally sustainable depends on meaningful environmental assessment tools, with life cycle assessments taking the lead.

In order for LCA to be expediently used for assessments of the environmental impact of agricultural products from different production systems, substantial extensions to the method are needed at different levels:

1. Models used as part of LCAs for estimating emissions from agriculture must be able to differentiate clearly between different agricultural production systems. Especially in the modelling of reactive nitrogen emissions, there is as yet no clarity of distinction between different production systems such as organic and conventional agriculture.
2. The assessment of environmental impacts in LCAs of agricultural products must be regionalised more strongly in order to be able to integrate local site factors into the assessment. This is of particular importance for a differentiated assessment of the impact of agricultural production on biodiversity and soil quality, but also applies to global warming and eutrophication.
3. The focus on eco-efficiency in the life cycle assessment of agricultural products and the environmental assessment of agricultural production systems based thereon must be reconsidered fundamentally. Given its product-based nature, it gives no indication as to whether a production system is indeed environmentally sound at the location at which it is being employed.
4. Overly intensive agriculture has the capacity to impair the functioning and maintenance of ecosystems in the long term. Any overexploitation of local environmental resources as a result of overly high production intensities must be given expression in the assessment. In conjunction with the greater regionalisation demanded under Point 2, local carrying capacities could be defined which could then determine maximum viable production intensities.

The integration of local site factors into life cycle assessments of agricultural products would also allow for the increased use of LCA findings as a spatial planning tool. LCA would thus make an important contribution to the development of regionally differentiated approaches to sustainable food production. Conflicting objectives with regard to local and global resources must be made transparent. This would also illustrate the quantities of food that could realistically be produced within existing resource constraints. This kind of information is in turn indispensable in order to steer food consumption onto a more sustainable course.

The integration of local site factors into life cycle assessments of agricultural products would allow for the increased use of LCA findings as a spatial planning tool and would help to reconcile agricultural production goals with societal protection goals such as biodiversity or the protection of watercourses and groundwater from pollution.

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