Greenhouse gas emissions related to organic feed production

Estimation of greenhouse gas emissions of organic feed ingredients by using the model FeedPrint.

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Samenvatting NL
In dit rapport worden de broeikasgasemissies van grondstoffen voor de biologische mengvoerproductie met behulp van een levenscyclusanalyse berekend. Het rapport beschrijft de dataverzameling en de invloed van databeschikbaarheid op de onzekerheid rondom broeikasgasemissies van grondstoffen voor de biologische mengvoerproductie. Tot slot worden in dit rapport aanbevelingen gedaan voor de verbetering van de berekening van broeikasgasemissies van grondstoffen voor de biologische mengvoerproductie.

Summery UK
In this report greenhouse gas emissions related to production of organic feed ingredients are computed by using life cycle assessment. The report describes data requirements, data availability, the uncertainty of these data, and the impact of these uncertainty on greenhouse emissions of organic feed ingredients. Finally, recommendations are given for a better estimation of greenhouse gas emissions of organic feed ingredients.

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Foreword

Binnen het Feed4Foodure project is de afgelopen jaren gewerkt aan verbetering van de methodiek en dataverzameling en -analyse voor het berekenen van broeikasgasemissies van mengvoerproductie. Hierbij is vooral aandacht besteed aan berekeningen voor grondstoffen voor de gangbare landbouw. Voor u ligt een rapport dat onderzoek presenteert naar de berekening van broeikasgasemissies van grondstoffen voor de biologische landbouw. Dit rapport is een eerste inventarisatie om broeikasgassen van grondstoffen voor de biologische landbouw te berekenen. Het rapport beschrijft de dataverzameling en de invloed van databeschikbaarheid op de onzekerheid rondom broeikasgasemissies van biologische mengvoerproductie. Tot slot worden in dit rapport aanbevelingen gedaan voor verbetering van broeikasgasemissieberekening voor biologische mengvoerproductie.

Voor dit onderzoek heeft de biologische mengvoersector data geleverd over type en herkomst van de voornaamste biologische grondstoffen die in Nederland gebruikt worden. Deze data zijn verwerkt door Nevedi. Hierbij willen we beiden voor hun medewerking bedanken.

Het onderzoek is gefinancierd door het onderzoeksprogramma Feed4Foodure. Feed4Foodure is een publiek private samenwerking tussen de Vereniging Diervoederonderzoek Nederland en Wageningen University & Research. Het Ministerie van Landbouw, Natuur en Voedselkwaliteit ondersteunt het programma via het TKI Agri&Food.

Summary

The European Commission has set the objective to increase the agricultural area under organic farming in the EU by 2030. In the Netherlands, 3.8% of agricultural land is used for organic production. Despite the role attributed to organic agriculture in making European food systems more sustainable in the Green Deal, little conclusions can be drawn about the environmental performance of organic food production.

In the Netherlands, greenhouse gas (GHG) emissions related to production of concentrates for the dairy sector are computed by the feed sector. The feed sector computes GHG emissions following the Product Environmental Footprint Category Rules (PEFCR) 'feed for food producing animals'. The underlying method applied is the life cycle assessment (LCA). In an LCA, all emissions related to all processes in a production chain are summed and expressed per kg product. In the Annual Nutrient Cycling Assessment (ANCA) tool, GHG emissions of the dairy sector are estimated. Emissions related to the production of feed ingredients are provided by the feed sector. Currently the feed sector does not differentiate between GHG emissions of conventional and organic feed ingredients in the ANCA tool. The impact of production of organic feed ingredients on GHG emissions might be different from conventional production. For a better calculation of GHG emissions of organic feed production and a better comparison between organic and conventional feed ingredients, information about the GHG emissions of organic feed production is important.

The objective of this study therefore was to compute GHG emissions related to production of organic feed ingredients. As little is known about GHG emissions related to organic feed production, we first explored data requirements and data availability for computing GHG emissions related to production of organic feed ingredients used in the Netherlands. Second we estimated GHG emissions of organic feed ingredients based on available data by using the model FeedPrint.

Data collection consisted of two steps. First, the organic feed sector was requested to provide data on the type of organic feed ingredients mostly used in the Netherlands, the origin of these feed ingredients and volumes of use within the Netherlands. The organic feed sector provided a total of 21 feed ingredients sourced from 23 countries. Second, for the selected crop-country combinations, we collected data about crop yields, fertilizer use, and use of other inputs such as energy for transport and cultivation. Based on current existing data sources, organic crop yield levels for our crop-country combinations were not available, and therefore the organic yield levels were based on conventional yield levels as implemented in FeedPrint corrected for differences between organic and conventional yields from literature. Organic crop-specific fertilizer application rates per hectare for each country could not be estimated on the basis of current existing data sources. Also, no data were available about the quantity of nutrients applied per hectare. We therefore estimated N application rate per type of organic crop with the assumption that the ratio between N application rate and crop yield in conventional production is similar to that in organic crop production. N application in conventional crop production consisted of N from animal manure and N from artificial fertilizer and was based on FeedPrint. We assumed that animal manure was the only fertilizer applied to organic crops. Therefore, to express N application rates in organic production in total N from animal manure, we converted kg N from artificial fertilizer to kg N from animal manure using the N fertilizer replacement value (NFRV) that consisted of a mixture of cattle, pig and poultry manure. No data were available about nitrogen fixation by leguminous crops, and therefore we may have overestimated the N application rates. GHG emissions per kg of feed ingredient were estimated using the FeedPrint model. As no guidelines for organic feed production exists, we followed the PEFcr guidelines for conventional feed production, and the background data (e.g. emissions related to energy production) of conventional crop production. We included emissions related to production and application of inputs for crop cultivation, on-field cultivation activities and soil emissions, post-harvest processes and transport, and land use change (LUC), and expressed emissions as CO_2-eq/kg product. It was assumed that animal manure had no economic value for the livestock system, and therefore no emissions related to livestock production were allocated to animal manure. We did account, however, for emissions related to application of animal manure.

In total, GHG emissions of 102 product-country combinations were estimated. GHG emissions ranged between 82 and 1,865 g CO_2-eq/kg product. Lucerne meal had highest emissions, whereas wheat

starch had lowest emissions. These emissions were based on a weighted average over several countries. Variation in GHG emissions of the same crops produced in different countries was substantial. For example, wheat produced in Germany had an impact of 333 g CO_2-eq/kg, whereas wheat produced in Spain had an impact of 640 g CO_2-eq/kg. Main emissions for all feed ingredients were from crop production. In crop production, the highest emissions were related to application of animal manure. The impact of the NFRV value on greenhouse gas emissions was analyzed and showed that NRFV of 53% (instead of 73% in the baseline situation) increased GHG emissions by 16% and 13% for respectively wheat and maize produced in Germany. The emissions increase because with a lower NRFV, more nitrogen from animal manure is needed to supply sufficient N to crops.

This study showed that data availability hindered a detailed assessment of the carbon footprint of organic feed ingredients. Due to the high uncertainty of input data and many assumptions taken in the current study, results cannot be used to compare organic feed ingredients with conventional feed ingredients. To include organic feed ingredients in the ANCA tool, data quality should be improved.

Guidelines (e.g. PEF) for organic feed production are needed that provide information about data collection, minimums of data requirements and quality, and methods to calculate environmental footprints of organic products.

For a better estimation of GHG emissions of organic feed ingredients, more and better data are required about:

- Type of fertilizer (animal manure, and other sources) used per type of organic crop in a country
- Amount of fertilizer and nutrients per hectare per type of organic crop in a country
- Input to produce fertilizers used in different countries
- Yield levels of organic crops in a country

1 Introduction

The European Green Deal provides a development pathway for food production towards 2030. This roadmap towards a greener economy supports a more efficient use of resources, recovery of biodiversity and a reduction of greenhouse gas (GHG) emissions. The role attributed to organic farming in the Green Deal is to contribute to achieving these goals (EC, 2020). Therefore, the European Commission prepares initiatives to boost organic farming. These initiatives aim to stimulate the demand for organic products by promoting these products to consumers, and to stimulate supply by supporting farmers in conversion to organic farming practices (EC, 2020). In line with the latter, the Commission has set the objective to increase the agricultural area under organic farming in the EU by 2030.

The turnover of organic products in the Netherlands increased in the period from 2016 to 2019 (Table 1). The turnover is mainly achieved in retail, where about 5,622 supermarkets, 315 organic speciality shops, and 11,500 other speciality shops (e.g. butchers, bakeries and vegetable stores) sell organic products to customers (Bionext, 2019a). Despite the increase in turnover of organic products, the market share of organic products remains relatively small. About 3.2 percent of the turnover in supermarkets is due to organic products (Bionext, 2019a). Especially popular are those food products that require little processing, and that have little scarcity in their supply of raw materials (Rabobank, 2020). Among the various product groups, the highest market share in supermarkets was achieved for eggs (16.62%), followed by fruits and vegetables (4.38%), dairy products (4.07%) and meat and meat products (3.67%) (Bionext, 2019a). In addition to retail, turnover of organic products in food services, such as restaurants, catering, and healthcare institutions, also increased, from 275 to 330 million euro (Table 1). The market share of organic products within foodservices is approximately 1,6% (Bionext, 2019a).

Also the number of organic farms increased, from 1,831 in 2016 to 2,076 in 2019 (Table 1). Most of these farms were certified organic (1,586 and 1,952 in 2016 and 2019 respectively), whereas a small number were in conversion from conventional to organic production (Bionext, 2017; Bionext, 2019a). Within the group of farms, the number of arable farms increased stronger than the number of animal farms (Bionext, 2019a).

In 2019, about 75,000 hectares of agricultural land were registered as organic, of which 69,000 hectares was certified organic and the remainder was in conversion from conventional to organic (Bionext, 2019a and CBS, 2020a). This means that 3.8% of agricultural land in the Netherlands is used for organic production. Most of this organic land is used as grassland (71%), followed by arable land (19%), horticulture (5%) and green fodder crops (4%) (CBS, 2020a).

Also the number of organically produced animals increased in the period from 2016 to 2019. The number of certified organic dairy cattle increased from over 49 thousand animals in 2016 to nearly 60 thousand animals in 2019, increasing its share from 1.6 to 2.4% (CBS, 2020b). The number of certified organically produced pigs increased with 50% to over 106 thousand animals in 2019 (CBS, 2020b). This is less than 1% of the total pig production in the Netherlands. The largest share of organic production is in poultry production, representing 3.9% of total poultry production in 2019 (CBS, 2020b).

Table 1 *Market figures and characteristics of organic production in the Netherlands between 2016-2019*

	2016	2017	2018	2019
Turnover of organic products in retail (million euro)	1446	1511	1666	1718
Turnover of organic products in foodservices (million euro)	275	305	321	330
Number of registered primary producers	1831	1930	2010	2076
Registered acreage (ha)	59765	69516	71351	75205

Sources: Data for 2016 and 2017 (Bionext 2017); data for 2018 and 2019 (Bionext 2019a)

Despite the role attributed to organic agriculture in making European food systems more sustainable in the Green Deal, little conclusions can be drawn about the environmental performance of organic versus conventional food production (Kirchmann et al. 2016; Meerburg et al. 2018). In their review, Kirchmann et al. (2016) concluded that comparative studies often fall short on creating good comparative conditions to ensure meaningful evaluations. These conditions include similar initial levels of soil fertility between plots, farms or regions, comparison of the same crop/crop rotation, and accounting for the amount of carbon and nutrients that are being imported to the system (Kirchman et al, 2016).

Since 2017, all Dutch dairy farmers are obliged to compute emissions of greenhouse gases related to production of milk using the Annual Nutrient Cycling Assessment (ANCA - KringloopWijzer) tool. An important input for this tool is the greenhouse gas (GHG) emission related to the production of concentrates. Concentrates consist of several feed ingredients produced around the world and contribute significantly to the total GHG emissions related to the production of milk and meat. In the Netherlands, GHG emissions related to production of concentrates are computed by the feed sector, which provides these data to dairy farmers as input to the ANCA tool. The feed sector computes GHG emissions following the Product Environmental Footprint Category Rules (PEFCR) 'feed for food producing animals' (EC, 2018). The underlying method applied is the life cycle assessment (LCA). In an LCA, all emissions related to all processes in a production chain are summed and expressed per kg product (e.g. kg feed, milk, or meat). The PEFCR feed, however, is developed for application to conventional feed, whereas guidelines for application to organic feed are lacking.
As no guidelines have been developed for organic feed production, the feed sector computes GHG emissions only for production of conventional feed ingredients. In addition, due to lack of data, it is assumed in the ANCA tool that GHG emissions related to production of organic feed ingredients are equal to that of their conventional congener. The impact of production of organic feed ingredients on GHG emissions might be different from conventional production. For a better estimation of GHG emissions of organic milk production and better comparison between organic and conventional feed ingredients, information about the impact of organic feed production on GHG emissions is important. The objective of this study therefore was to estimate GHG emissions related to production of organic feed ingredients. As little is known about GHG emissions related to organic feed production, this research first explores data requirements and data availability for estimating GHG emissions related to production of organic feed ingredients used in the Netherlands. It furthermore addresses methodological choices specifically related to organic feed production.

1.1 Goal of this study

This project has the objective to estimate GHG emissions for a selected group of organic feed ingredients produced in EU and non-EU countries.

1.2 Readers guide

In chapter 2, the main differences between organic and conventional crop production are described, and data collection and methods to estimate GHG emissions of organic feed ingredients are explained. Chapter 3 shows the results of our GHG calculations of organic feed ingredients, and of an analysis regarding the use of animal manure. Chapter 4 discusses the results and gives conclusions and recommendations.

2 Material and methods

An LCA was performed to estimate GHG emissions of organic feed ingredients using the FeedPrint tool developed by Vellinga et al. (2013). We accounted for emissions of greenhouse gases (GHG) (CO_2, CH_4 and N_2O) from 'cradle-to-Dutch dairy farm'. We therefore accounted for emissions related to production and application of inputs for crop cultivation, on-field cultivation activities and soil emissions, post-harvest processes and transport, and land use change (LUC).

Regulations for organic production are different compared to regulations for conventional production. Therefore, we first describe the main differences between organic and conventional crop production. Thereafter, we describe data collection, and the estimation of GHG emissions.

2.1 Organic crop production

Essential elements of organic crop and animal production are, among others: nutrient recycling through use of animal manure and composting, and nitrogen fixation by leguminous crops, such to exclude artificial fertilizers and increase soil fertility and soil structure; biodiversity increase to enhance natural pest suppression, such to reduce or exclude chemical inputs; animal grazing to limit the occurrence of weeds; and implementation of crop rotation to optimally align nutrients to the need of following crops (Kristiansen Eds. 2016). The main difference between organic and conventional crop production is the exclusion of artificial fertilizer, synthetic pesticides and genetically modified organisms (GMO).

Products are certified as 'organic' if produced according to the legal guidelines established by the European Union and the Dutch government. These guidelines describe general principles for a holistic design of the food production process, as well as specific regulations for the cultivation of crops, the husbandry of animals, and the production of aquaculture animals and seaweed (EG, 2007). The legal guidelines furthermore list the types of inputs (e.g. fertilizers, pesticides, disinfectants, feed and food additives) that are permitted throughout the organic production chain. In the Netherlands, the organisation SKAL monitors and certifies organic products that comply to the rules. In addition to European and national laws, SKAL has its own regulations to which farmers have to comply, and, hence, SKAL regulations are part of the total package of regulations for organic production in the Netherlands (Skal, 2017). One regulation that SKAL implements in addition to European and national laws, is that at least 70 % of nitrogen input originates from so called category A fertilizers (e.g. organic animal manure or others). In the current project, most organic crops are produced outside the Netherlands, and therefore we do not account for this regulation in the current study.

2.2 Data collection

For the estimation of GHG emissions, first data about organic feed production was collected. This consisted of two steps. First, the organic feed sector was requested to provide data on the type of organic feed ingredients mostly used in the Netherlands, the origin of these feed ingredients and volumes of use within the Netherlands. Second, input data to calculate GHG emissions of these feed ingredients were collected.

Type of organic feed ingredients and country of origin

A questionnaire was made by Wageningen Livestock Research (WLR) and sent by Nevedi to organic feed companies in the Netherlands. In the questionnaire, these companies were asked to indicate which feed ingredients are mostly used in the Netherlands in 2018 and 2019, the volume of these feed ingredients, and from which countries they originate. Returned data were processed by Nevedi. The most important feed ingredients were selected based on their volume of use in the dairy sector in the Netherlands. In total, 21 feed ingredients sourced from 23 countries were selected by Nevedi and sent to WLR (Table 2 and 3). In total, this resulted in 102 product-country combinations.

Table 2 *Organic feed ingredients selected for this study.*

Feed ingredient	Feed ingredient
Maize	Lupins
Spelt	Peas
Spelt husks	Sunflower seed expeller
Oats	Linseed expeller
Barley	Rape seed expeller
Rye	Soya bean expeller
Wheat	Sugarbeet pulp
Wheat middlings	Field beans
Triticale	Lucerne (alfalfa) meal
Horse beans	Molasses sugarcane
	Wheat starch

Note: Type of organic sunflower seed expeller was unclear and therefore GHG emissions of organic sunflower seed expeller was estimated as dehulled, partly dehulled, and hulled.

Table 3 *Countries of origin of selected organic feed ingredients.*

Country of production	Country of production
Spain	Ukraine
Slovakia	Russia
Hungary	Moldavia
Czech Republic	Romania
Baltic states	Poland
Denmark	Lithuania
Austria	Germany
Paraguay	China
Thailand	Italy
India	France
Kazakhstan	Belgium
	Netherlands

Input data

For the selected crop-country combinations, data were collected about crop yields, fertilizer use, and use of other inputs such energy for transport and cultivation. The following datasets, websites, and organizations were analysed or approached to find inputs: FAOSTAT (FAO, 2020), EUROSTAT (EU, 2020), FiBL Statistics (FiBL, 2020), Bionext (Bionext, 2019b), as well as scientific and non-scientific literature.

Crop yields

In our data collection for country-specific multiple-year average yield levels of organic crops (kg/ha), the following criteria were defined:

- For reasons of consistency, country-specific multiple-year average yield levels of organic crops originate from one data source. If no such data source is available, a combination of data sources/literature can be used

- If no country-specific multiple-year average yield levels of organic crops can be found, yield levels are estimated based on organic crop area (ha) and organic crop production (ton) per country
- If organic yield levels cannot reasonably be estimated based on organic crop area and crop production, organic yield levels are estimated based on the differences between organic and conventional yields, here referred to as relative yields (Ponti et al. 2012).

As we are interested in both EU and non-EU countries, we first searched in FAOSTAT and FiBL Statistics, as these are internationally oriented, followed by EUROSTAT. In these three databases, we found no, or only fragmented data about organic crop yields.

FAOSTAT provides yield levels of conventional crop production only, and, hence, no data on organic crop yields were found. FiBL Statistics used organic data from EUROSTAT. As organic crop yields for this study were lacking in FAOSTAT, and FiBL Statistics used EUROSTAT, we subsequently explored data in EUROSTAT. From this database, we calculated organic crop yield levels per hectare per country from the given organic production volume (ton) and related land area (ha) per crop per country. Due to unavailable data on organic production volumes, we could not calculate organic crop yields for Germany, Austria, and Denmark, nor for organic maize, triticale, lucerne, peas, horse beans, and lupins. Maize and lucerne, for example, are grouped under 'Plants harvested green', and, hence, crop specific data was missing. The calculated organic crop yield levels were compared with conventional yield levels provided by FAOSTAT. The resulting organic–conventional relative yields are presented in Appendix 1 Table A.1.The organic–conventional relative yields presented in Appendix Table A.1 show high variation between countries. For linseed, for example, ratio ranged between 1% for Spain and 358% for Belgium. This range is substantially larger than the range found in Ponti et al. (2012), who's organic–conventional relative yields ranged between 65-105% for the feed ingredients analysed in this study. Because of this high variation, and because of the incompleteness of data, we decided not to use Eurostat for our calculations.

Furthermore, in our literature search, we found scarce and fragmented data on yield levels of organic crops, representing data for a specific year and specific crop farming situations, instead of multiple-year average yield levels of organic crops representative for a specific country.

As organic yield levels for our crop-country combinations cannot reasonably be estimated from existing data sources, we estimate the organic yield levels based on conventional yield levels as implemented in FeedPrint corrected for organic–conventional relative yields as presented by Ponti et al. (2012) (Table 4).

Table 4 *Relative yields between organic and conventional crop production (Ponti et al., 2012).*

Crop	**Relative yield**	
Maize	89%	Mainly North-America
Soybean	92%	Mostly from USA
Wheat	73%	includes summer, spring, winter and durum wheat
Lucerne	85%	other fodder crops
Triticale	81%	Other cereals
Peas, dry	85%	
Rye	76%	includes spring, fall and winter rye
Barley	69%	includes spring, fall and winter barley
Oats	85%	
Broad beans, horse beans, dry	88%	Pulses
Sugar beet	105%	Other root and tuber crops
Sugar cane	80%	total average Ponti et al.
Lupins	85%	other fodder crops
Sunflower seed	77%	Mainly North-America
Linseed	65%	From Canada
Rapeseed	82%	Other oilseed crops
Spelt	73%	Assumed same as wheat

Fertilizer inputs
The impact of producing and applying fertilizers on GHG emissions related to crop production, is based on crop-specific fertilizer application rates per hectare for each country. However, no database exists that registers this type of data. In addition, only very limited and fragmented data were available in literature, providing an incomplete and inconsistent dataset. Based on the mineral flow analysis performed for the Dutch organic agricultural system (Bionext, 2019b), it would be possible to compose a fertilizer mix for the Netherlands. However, most crops included in this study were produced outside the Netherlands, and given the differences in manure regulation in organic agriculture between the Netherlands and other countries, the Dutch fertiliser mix is assumed unrepresentative for other countries.

Organic crop-specific fertilizer application rates per hectare for each country could not be estimated on the basis of current existing data sources. Also, no data were available about the quantity of nutrients applied per hectare. The following approach has been chosen to estimate the N input for organic crops:

a) The N input in organic crops comes from animal manure only, taking into account the Nitrogen Fertilizer Replacement Value (NFRV), this is the N that is or becomes available in mineral form and can be taken up by the plant. Of course, N fixation by leguminous crops is important for crop growth, but not relevant for calculation of N_2O emissions. The NFRV value of animal manure in organic farming systems takes into account the long term mineralization.
b) The ratio between N input and crop yield is the same for organic and conventional crop production. See Equation 1.
c) Data are available about conventional production: available N from manure (see also equation 3), artificial N and crop yield are derived from the FeedPrint database. The conversion of total N from animal manure to available N is performed by using the NFRV. Data about organic crop yields were based on relative yields between organic and conventional crop production (Table 4).
d) The N input in organic crops is calculated, using b) and c). Equation 1 is converted to equation 2. The result of this equation 2 is the available mineralized N input from animal manures.
e) The final step is to convert the calculated available mineralized N input to amounts of total N from animal manure by dividing by the NFRV. See Equation 4 and Table 5.

Ratio between N input and crop yield is the same for organic and conventional crop production (Eq. 1)

$$\frac{N - input_{organic}}{DM - yield_{organic}} = \frac{N - input_{conventional}}{DM - yield_{conventional}}$$

Conversion of this formula gives: mineralized N input from animal manure: (Eq. 2)

$$N - input_{organic} = \frac{DM - yield_{organic}}{DM - yield_{conventional}} * N - input_{conventional}$$

In which the N-input-conventional is: (Eq. 3)

$$N - input_{conventional} = (Manure - N_{conventional} * NFRV_{conventional}) + Artificialfertilizer - N$$

Nitrogen application rates (kg N/ha) from animal manure per hectare in organic crop production were estimated as: (Eq. 4)

$$Manure - N_{organic} = N - input_{organic} / NFRV_{organic}$$

where NFRV is N uptake from animal manure as percentage from the uptake from artificial N fertilizer (Table 5). We assumed that the fertilizer mix consisted of solid cattle manure (25%), cattle slurry (25%), pig slurry (25%), and poultry manure (25%) (Table 5). The average NFRV of this fertilizer mix was 73%, implying that 1 kg N from this fertilizer mix is equivalent to 0.73 kg N from artificial fertilizer (Table 5). NFRV conventional and NFRV organic were assumed to be similar.

Table 5 *Share of nitrogen from animal manure applied per hectare, nitrogen fertilizer replacement value (NFRV) per type of animal manure.*

	Share of N in fertiliser mix	NFRV [1]
Cattle Slurry	0.25	0.75
Cattle Solid manure	0.25	0.55
Pig slurry	0.25	0.85
Poultry litter	0.25	0.75
Total	1.00	0.73

[1] (Schröder & van Dijk, 2019)

We did not account for application of phosphorous and potassium, because no data were available about type of fertilizers and application rates. The input of lime (kg/ha) was assumed equal to that in conventional production, though corrected for the organic–conventional relative yields (Table 4). Post-harvest inputs per ton of product, such as energy for transport and energy for storage and processing, were assumed equal to that in conventional production. We assumed that crop processing occurred in the Netherlands.

2.3 Estimation of greenhouse gas emissions

GHG emissions per kg of feed ingredient were estimated using the FeedPrint model (Vellinga et al., 2013). This tool follows the PEFcr guidelines for conventional feed production (EC, 2018). As no guidelines for organic production exists, we follow the PEFcr guidelines for conventional feed production and the same background data (e.g. emissions related to energy production) as for conventional crop production. The model accounts for emissions from 'cradle-to-Dutch dairy farm'. Impacts of processes yielding multiple products (e.g. cultivation of a hectare of wheat) were assigned to output products (e.g. wheat grain and wheat straw) based on economic allocation factors as included in FeedPrint. It was assumed that animal manure had no economic value at the livestock farm gate, and therefore no emissions related to livestock production were allocated to animal manure. We did account, however, for emissions related to application of animal manure. On-field emissions were calculated according to the PEFcr Feed (EC, 2018).

Emissions of CO_2, CH_4 and N_2O were expressed as CO_2-equivalents based on their equivalent factor (1 for CO_2, 34 for biogenic CH_4, 36.75 for fossil CH_4, 298 for N_2O). For each feed ingredient, a weighted average carbon footprint was estimated based on the relative volume per country of origin.

2.4 Impact of a different NFRV

Type and quantities of fertilizers have an important impact on GHG emissions in conventional crop production. Yet information about fertilizer use in organic crop production was missing. We therefore made several assumptions about fertiliser use. In this scenario, we show the impact of assumptions about the NFRV of animal manure.

The NFRV is affected by multiple factors, including crop type, soil type, manuring history, and method and time of application (Hijbeek et al., 2018). As such, a broad range of NFRV can be expected in practise, and it is worthwhile exploring the impact of the NFRV value on greenhouse gas emissions. As mentioned in section 2.2, we used NFRV of 73% in our baseline situation. For this analysis, an alternative NFRV was calculated based on first year NFRV values from Schröder & van Dijk (2019) (Appendix Table A.2). The alternative NFRV was 53%. In PEFcr Feed, NH_3 emissions (contributes indirectly to N_2O emissions) from animal manure (0.24 kg NH_3/ kg N manure applied) and artificial fertilizer (0.12 kg NH_3/ kg N fertilizer applied) are different per kg N applied, but N_2O emissions from animal manure and artificial fertilizers (0.022 kg N_2O/ kg N fertilizer applied) are the same per kg N applied. Due to lower NFRV, a higher amount of animal manure had to be accounted for in the alternative situation, to assure sufficient nitrogen application rates to crops. This will have an impact on the NH_3 and N_2O emissions from fertilizers. Maize and wheat produced in Germany were used as an example to show the impact of a different NFRV.

3 Results

GHG emissions related to the production of primary organic crops, and of co-products and processed feed ingredient, are presented in Figure 1 and 2 respectively. The emissions are weighted averages of their countries of origin. We distinguish between emissions from feed production (e.g. fertilizer application and energy use), land use change (LUC) (e.g. deforestation), and transport. For primary crops, spelt had the lowest emissions (434 g CO_2-eq/kg product) and lupine the highest (1105 g CO_2-eq/kg product) (Figure 1). Variation in GHG emissions of the same crops produced in different countries was substantial (results not shown). For example, wheat produced in Germany had an impact of 333 g CO_2-eq/kg, whereas wheat produced in Spain had an impact of 640 g CO_2-eq/kg. Main emissions for all feed ingredients were related to feed production, mainly due to application of animal manure. For wheat and maize produced in Germany, for example, application of animal manure contributed for 48% and 44% to total emissions respectively (results not shown). The contribution of transport to the total emissions ranged from 6% to 15%. This variation was due to different countries of origin and related transport distances of crops. LUC hardly occurred in the countries of origin, and therefore for most crops contribution of LUC to total emissions was low.

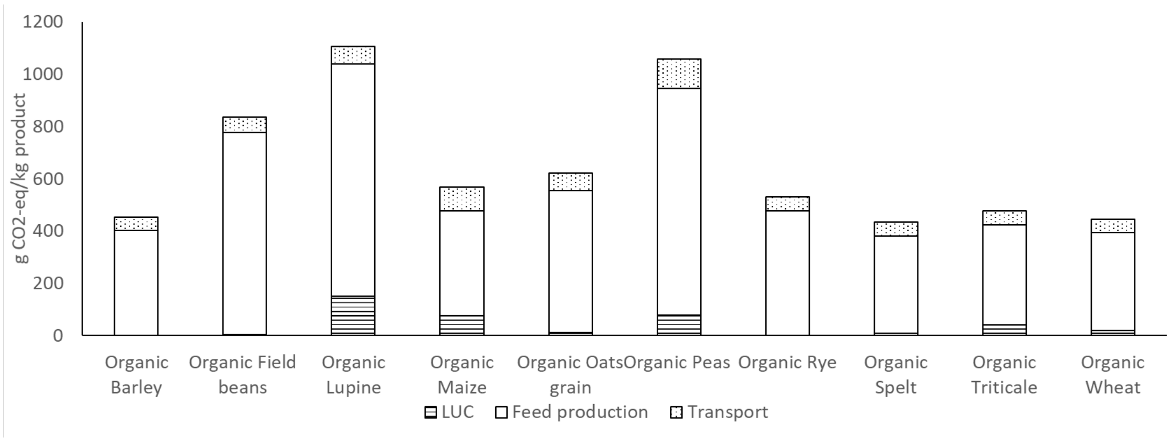

Figure 1 *Greenhouse gas emissions (g CO_2-eq/kg) from cradle-to-Dutch dairy farm of primary organic crops.*

For co-products and processed feed ingredients, the emissions ranged between 82 and 1865 g CO_2-eq/kg product (Figure 2). Lucerne meal had the highest emissions, whereas wheat starch had the lowest emissions. Emissions of lucerne meal mainly originated from energy use for processing and drying (>85%). Emissions from transport varied between products due to different countries of origin and related transport distances of crops. For the given co-products and processed feed ingredients, LUC hardly occurred in the countries of origin, and therefore the contribution of LUC to total emissions was low.

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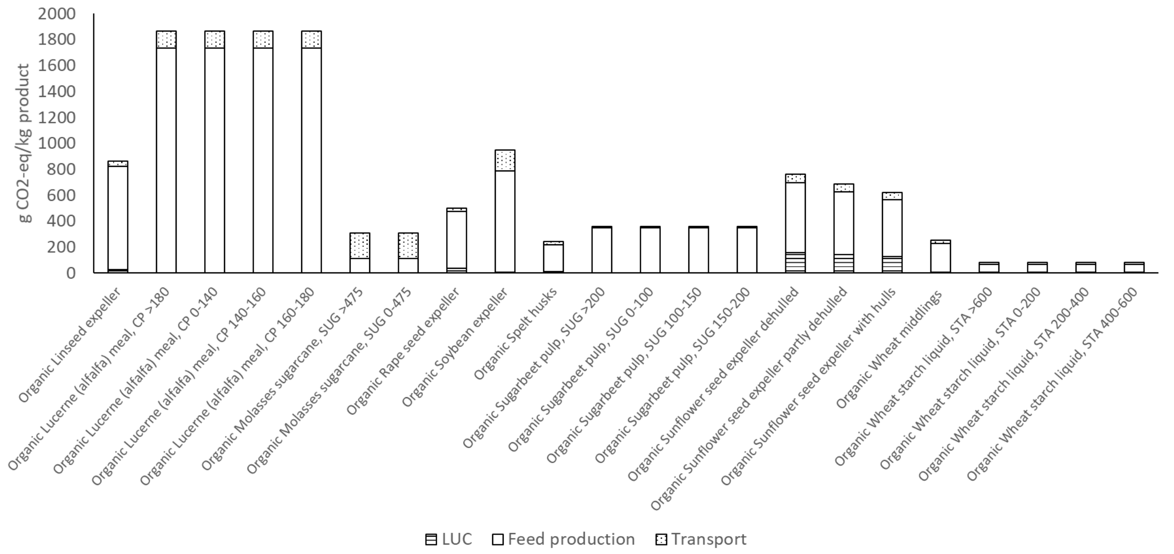

Figure 2 *Greenhouse gas emissions (g CO_2-eq/kg) from cradle-to-Dutch dairy farm of co-products and processed feed ingredients from organic crops.*

3.1 Impact of a different NFRV

The impact of NFRV on GHG emissions is shown by replacing NFRV of 73% (in the baseline situation) by NRFV of 53% (Figure 3). NFRV of 53% increased GHG emissions by 16% and 13% for respectively wheat and maize. The emissions increase because with a lower NFRV, more nitrogen from animal manure is needed to supply sufficient active N to crops. Hence, an increase in total N from animal manure increases the emissions from animal manure per kg feed ingredient.

N_2O emissions per kg N from artificial fertilizer and per kg total N from animal manure are the same (EC, 2018). Including specific N_2O emission factors for artificial fertilizer and animal manure will affect the impact of animal manure on total emissions. This occurs in the ANCA tool for calculation of emissions of feed production on the dairy farm. However, these emission factors are not available for all other countries that produce feed ingredients for the Dutch dairy farm and therefore is difficult to implement.

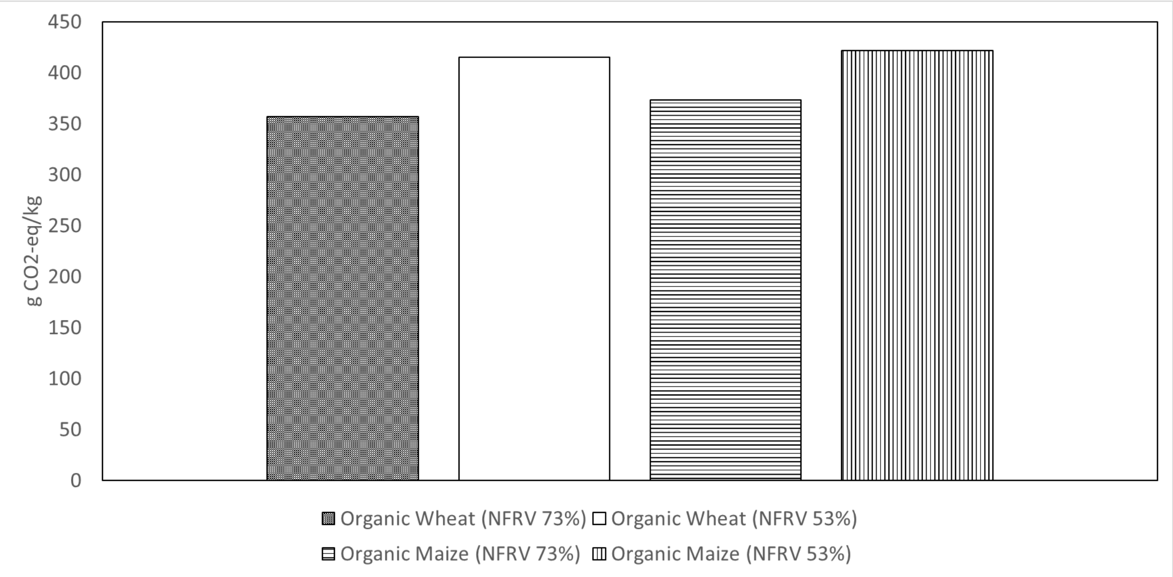

Figure 3 *Impact of an alternative nitrogen fertilizer replacement value (NFRV) on greenhouse gas emissions per kg maize and wheat produced in Germany.*

4 Discussion and conclusions

This study estimated GHG emissions of several organic feed ingredients produced in different countries, mainly European. Despite its growth over the last decades, the organic farming sector is relatively small compared to the conventional sector. The European Commission has set the objective to increase the agricultural area under the organic farming in the EU by 2030. This may increase the scale of organic agriculture, and therewith increase the importance of good estimations of environmental impacts of organically produced products. In this study, we assessed data availability to estimate GHG emissions related to the production of organic feed ingredients fed to dairy cows in the Dutch sector.

For our data search, we assessed databases and literature resources, and contacted organisations that are related to the agricultural sector. We concluded, however, that data availability of organic crop production is very limited. Specifically, we found that data about type and quantity of fertilizers used, and data about organic crop yields, were hardly available and fragmented. Limited availability of data about organic production has also been addressed by research institutes specialised in organic agriculture (Bionext, 2019b; Willer et al., 2021). Due to insufficient data availability, many assumptions were made to calculate GHG emissions of organic feed ingredients.
Fertilizer production and application have a substantial impact on total GHG emissions. Therefore, data about, among others, the type and amount of fertiliser used, are important in GHG estimations. In our study, we assumed, for example, that animal manure had no economic value. Therefore, we did not assign emissions to the production of livestock to animal manure. Assigning economic value to animal manure will increase the emissions per kg of feed ingredient. Also other types of fertilizers, such as compost, do have emissions for the production of this fertilizer. Therefore, type of fertilizers used in organic feed production and how emissions are allocated to animal manure have an important impact on GHG emissions of feed ingredients.
Several assumptions were made to estimate the total nitrogen application rates. First, nitrogen application rates were based on nitrogen application rates from artificial fertilizer and animal manure in conventional crops. Moreover, we assumed a linear relation between N input from fertilizers and N output from crops and therefore corrected for organic-conventional relative yields. However, when organic (or conventional) farmers use more leguminous crops, the amount of N applied may be lower, resulting in lower N input and lower GHG emissions. Second, our scenario showed that NFRV had an impact on amount of total N applied from animal manure and consequently on GHG emissions. The NFRV is affected by multiple factors, including crop type, soil type, manuring history, and method and time of application (Hijbeek et al., 2018). These variables were not included in the study due to lack of data, and therefore, we may have over- or underestimated the amount of N applied. For many countries, the amount of N from animal manure applied in conventional crop production is estimated on a national level and not on crop specific level, due to lack of data. The total N from animal manure is divided over the total agricultural area in that country. Consequently, all crops in a specific country have the same N application rate from animal manure per hectare and this had an impact on the results. For example, in our analysis leguminous crops also have N applied from animal manure while in practice these crops may not need this. These leguminous crops were also cultivated in countries with a low yield, resulting in relatively high GHG emissions. On the other hand, these crops may need animal manure for supply of phosphorous and potassium. In that case, emissions from applied nitrogen are a negative bycatch. This example also shows the need for better data about fertilization, also in conventional crop production.

Phosphorus and potassium application rates were not accounted for. No data were available about the N, P, K ratio of organic animal manure in the countries analysed in this study. Therefore, we could not estimate whether amount of P_2O5 and K_2O applied by animal manure was sufficient for the related growth of the crops. If additional P and K fertilizers are required GHG emissions related to the production of these fertilizers (e.g. vinasse kali) will also have to be accounted for. This will increase GHG emissions of crop production. We conclude that more specific data are required about fertilizer use in organic crop production, before good estimates of GHG emissions of organic crop production can be made. We suggest that type and fertilizer application rates per type of organic crop in a country are monitored by primary producers, and are subsequently aggregated and published in reviewed databases. If this way of data collection is too intensive, then less intensive ways of collection, such as for example data collection on a national scale may be a good alternative.

Limited information was available about yields of organic crops. Organic crop yields were therefore estimated from yield levels of conventional crops, and organic-conventional relative yields (Ponti et al., 2012). The yield ratios presented by Ponti et al. (2012) were, however, not country specific and were not available for all crop types. This may have resulted in an over- or underestimation of organic crop yield.

This study only estimated GHG emissions related to organic feed production. To comply to a PEF standard also other environmental impacts should be included. Currently organic agriculture is not included in the PEFcr feed for conventional feed production (EC, 2018). When the share of organic agriculture increases, guidelines to estimate environmental impacts of organic products becomes more important for a comparison between organic products but also between organic and conventional products. This study showed that a lot of data about organic crop yields and type and quantity fertilizers, that are essential for estimation of GHG emissions, are currently hardly available. Guidelines can also provide guidance on how to handle the limited data availability or may provide background datasets when specific data are not available. Moreover, in these guidelines also other roles of (organic) agriculture (e.g. ecoservices and biodiversity, animal welfare, and different functional unit (Van der Werf et al., 2020)) should be included for a more complete analysis of different production systems. Moreover, if you want to compare products from different sectors (e.g. organic vs conventional, or animal vs plant) and stimulate consumers to buy specific products based on the carbon footprint, other methods than LCA should be considered. LCA expresses emissions per kg product and does not include the impact of changes in one sector on other sectors. Moreover, in LCA allocation is used to divide emissions of one crop to several (by)products based on the economic value of these products. By-products used in the livestock sector have a low economic value and therefore low GHG emissions per kg product. An increasing demand for a by-product may affect the economic value, which increases the emissions allocated to this by-product and subsequently the emissions of that livestock product. However, total emissions of the agricultural sector did not change. By expressing emissions per kg product and per sector, this is not shown. LCA is a good method for analyses of a sector or a product and users of LCA results should be aware of the meaning and usage of these results.

Recommendations

This study showed that data availability hindered a detailed assessment of greenhouse gas emissions of organic feed ingredients. Due to the high uncertainty of input data and many assumptions in the current study, results cannot be used to compare organic feed ingredients with conventional feed ingredients and we recommend not to include these results in the ANCA tool (Kringloopwijzer). To include organic feed ingredients in the ANCA tool, data quality should be improved. In addition, (PEF) guidelines for organic feed production are needed that provide information about data collection and minimum of data required, and methods to calculate environmental footprints of organic products.

For a better estimation of GHG emissions of organic feed ingredients, more and better data are needed about:

- Type of fertilizer (animal manure, and other sources) used per type of organic crop in a country
- Amount of fertilizer per organic crop in a country
- Input to produce fertilizers used in different countries
- Yield levels of organic crops in a country

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Appendix

Table A1. Organic–conventional relative yields for a selection of crop-country combinations. Organic yields were calculated from EUROSTAT (average 2016-2018), and conventional yield from FAOSTAT (average 2014-2018). As these organic–conventional relative yields have a substantially wider range than the organic–conventional relative yields presented by Ponti et al. (2012), these organic–conventional relative yields were not used for further calculations. The table indicates, for example, the yield of organic wheat cultivated in Belgium is 40% of the conventional yield.

Country	**Wheat**	**Rye**	**Barley**	**Oat**	**Sugar beet**	**Rapeseed**	**Sunflower seed**	**Linseed**	**Soy beans**
Belgium	40%	107%	41%	54%	no data	42%	no data	358%	no data
Czechia	39%	49%	38%	61%	30%	19%	37%	62%	103%
Spain	31%	48%	39%	54%	11%	19%	31%	1%	65%
France	no data	no data	26%	44%	no data	25%	48%	no data	59%
Italy	77%	63%	57%	78%	9%	53%	63%	235%	53%
Lithuania	38%	67%	43%	73%	60%	23%	no data	103%	no data
Hungary	45%	41%	32%	43%	24%	46%	57%	61%	48%
Nether lands	59%	71%	60%	80%	15%	no data	no data	no data	no data
Poland	42%	57%	36%	61%	1%	10%	104%	51%	37%
Romania	54%	45%	29%	62%	34%	48%	59%	95%	56%
Slovakia	47%	61%	44%	104%	81%	36%	72%	no data	31%

Table A2. Input for scenario of different nitrogen fertilizer replacement value (NFRV): share of nitrogen from animal manure applied per hectare, NFRV per type of animal manure.

	Share of N in fertiliser mix	**NFRV** [1]
Slurry cattle	0.25	0.55
Solid cattle	0.25	0.25
Pig slurry	0.25	0.75
Poultry	0.25	0.55
Total	1.00	0.53

[1] (Schröder & van Dijk, 2019)