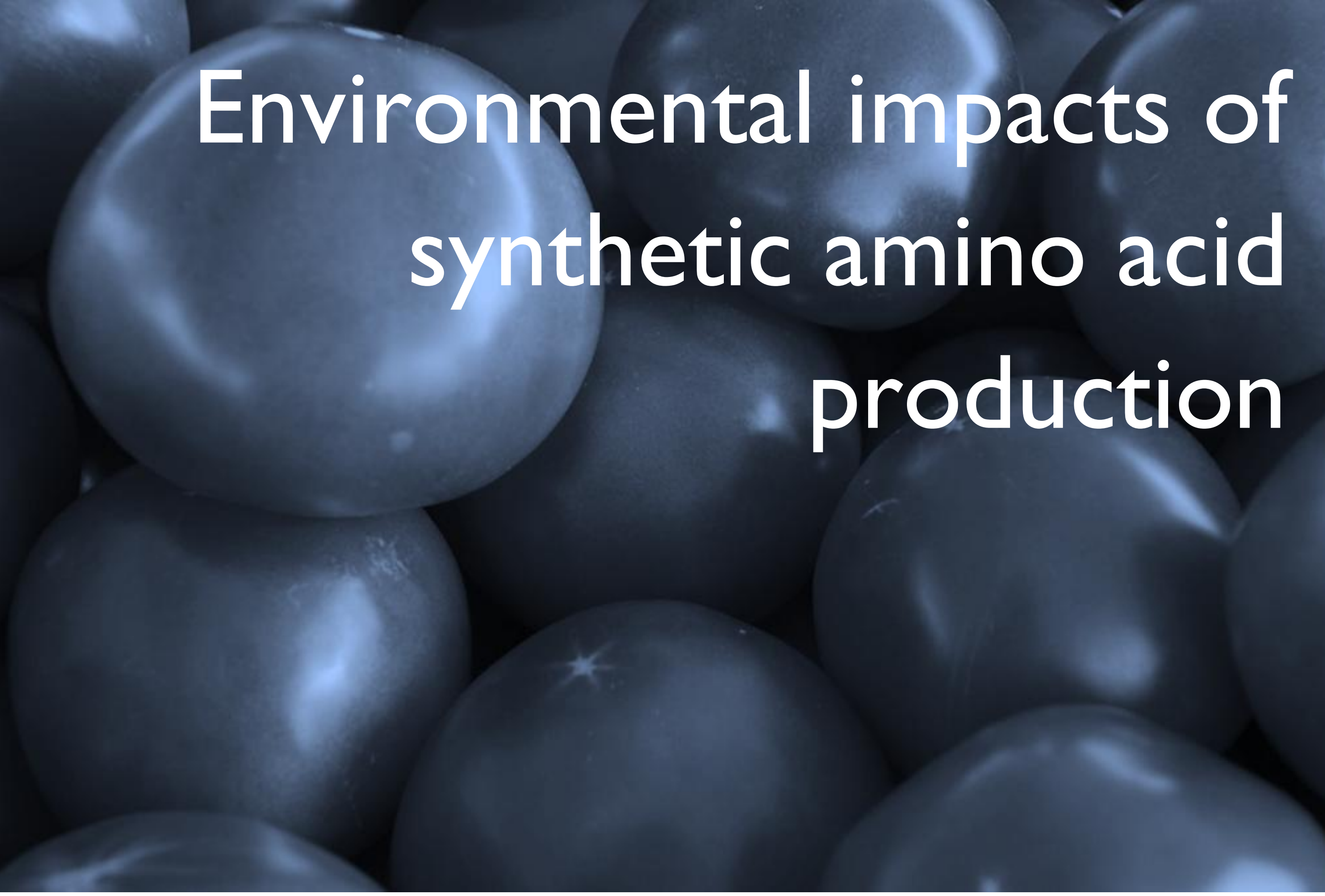
Environmental impacts of synthetic amino acid production



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Contents

1. Introduction

Novozymes is working on LCA's to calculate the environmental impact of using enzyme technology in a wide range of industries, including the animal feed industry. At this moment, Novozymes is performing a study on the use of a protease to improve the nutritional value of feed for broilers. For this study LCA information is needed about essential amino acids that are widely used in animal feed: L-lysine, DL-methionine and L-threonine. This document describes the survey to obtain this information and the resulting environmental impact figures concerning the three amino acids performed by Blonk Milieu Advies (BMA).

Chapter 2 provides information on the approach, methodology used and data that were applied for the analysis. In Chapter 3 figures of production of the amino acid production are presented and in Chapter 4 the calculated environmental impacts are reported and discussed.

2. Approach

2.1. Goal

The aim of this inventory is to collect environmental impact assessment data for the amino acids L-lysine, L-threonine (both bio-synthetic produced) and DL-methionine (synthetic produced) used in animal feed. This information will be used by Novozymes in a LCA on the impact of protease use in broiler feed.

2.2. Impacts on environmental categories

The following impact categories are taken into account in this study:
1) climate change,
2) fossil fuel consumption,
3) eutrophication,
4) acidification,
5) photochemical smog formation,
6) land use

The impacts on the different categories are calculated and expressed according to the recently developed methodology ReCiPe (Goedkoop *et al.* 2009). The ReCiPe method is a follow up of earlier LCA impact-methodologies, such as CML-2001 and Eco-indicator-99. The ReCiPe method involves improvements on different aspects; for example, it includes a more complete set of substances that may cause environmental impacts and it contains a better toxicity impact modelling (see also www.lcia-recipe.net).
The impacts on the different categories are expressed on the mid-point level[1], see Table 2.1 .

Table 2.1. The environmental impact categories analyzed in this inentory

impact category	unit	Description
Climate change	Kg CO2 eq.	The contribution to climate change by greenhouse gases as carbon dioxide (CO_2), methane (1 kg CH_4 equals 25 kg CO2 eq, nitrous oxide (1 kg N_2O equals 298 kg CO2 eq)
Fossil fuel consumption	Kg oil eq.	Use of fossil energy sources. One kg oil equivalent equals 42,017 MJ from a fossil energy source like natural gas, diesel, coal etc.
Acidification	g SO2 eq.	Contribution to terrestrial acidification by for instance deposition of ammonia
Eutrophication	g P eq.	Contribution to the eutrophication of fresh water by leaching/emission of nutrients as nitrogen and phosphorus. One kg P eq. equals 0.989kg PO4
Photochemical smog formation	g NMVOC	Contribution to formation of summer smog, expressed in g Non Methane Volatile Organic Compounds (NMVOC). One kg ethene (C2H4) corresponds to 1.689 kg NMVOC
Land use	m2a	The sum of agricultural and urban land use expressed in m2 * year

Impacts are calculated according the attributional approach. Impacts according to system expansion are considered and explained in section 2.6 Data.
Calculations of the environmental impacts are performed by using the LCA software 'Simapro7' (see also www.pre.nl/simapro).

[1] On mid-point level the impact is stated for each individual impact category. The mid point impacts can be weighed and summed to three end point indicators: impact on ecosystems, impact on human health and depletion of resources.

2.3. Functional unit

The functional unit is 1000 kg synthetic produced amino acid (Lysine.HCl, Threonine 98% pure crystalline threonine containing 2% water and 100% D,L-methionine), at the gate of the production site.

2.4. System boundaries

The system studied concerns the cradle to gate production of the amino acids. Whereas the production of components used in the production process represents the cradle, the starting point and the amino acids ready to leave the production site as end point of the studied system. The use of the considered amino acids is beyond the system boundary defined in this inventory (see Figure 2.1).

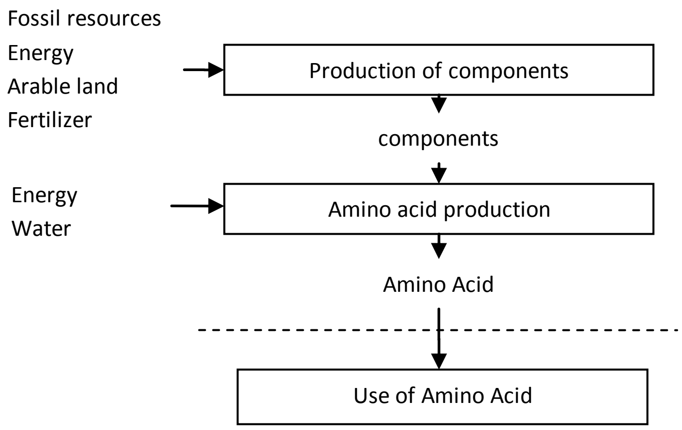

Figure 2.1 Schematic process map for the production of amino acids considered in this inventory, the dotted line represents the system boundary.

The production of amino acids is located in Europe. To analyse the impact of specific location in Europe three scenarios representing three possible countries of production are studied: Germany, Denmark and France.

In the life cycle assessment we excluded capital goods and office services[2]. Components used in minor quantities for the production of L-lysine and L-threonine as vitamins, amino acids, salts, antibiotics, and nitric acid for cleaning are excluded from the inventory because the expected share to the impact is very small relative to the effort to inventory the impacts. The disposal of waste water with diluted organic material is also excluded from the inventory because the impact is expected to be very small.

2.5. Allocation

In this LCA study, we followed the allocation rules as recommended in the Dutch horticulture protocol for carbon footprinting (Blonk et.al., 2009). This means that in case of co-production, where both products have a rather similar functionality and characteristics, physical allocation was applied to divide the environmental burden of a process and the upstream production chain to the co-products. In case of an obvious distinct functionality and characteristics, economic allocation was applied. Economic allocation is applied, for instance in case of the production of Corn Steep Liquor as co-product of maize processing.

[2] The exclusion of capital goods and office services is according the carbon footprint protocol PAS2050.

2.6. Data

2.6.1. *Primary activity data*

Data about the production of the amino acids are obtained from consultancy, literature and internet. The data represent a best estimate of an average commercial scale of operation in Europe. The level of technology can be considered state of the art.
Detailed information about the synthetic production of D,L-methionine was hard to get. We have found only one person who was willing us to tell about the energy use of D.L-methionine production, but was not willing to explain exactly how D,L-methionine is produced, claiming this is confidential information (Keuken, 2010). From literature (Binder, 2006, Erikson et al, 2005; Drauz et al, 2006 and anonymous II) we constructed a production scheme that was used for estimating the environmental impact factors. For D,L-methionine, it is the best estimate we could make.
There is much more (public) literature about the synthetic production of L-lysine and L-threonine, most of them write about experiments at laboratory scale and the scientific development of strains that produce amino acids with sufficient yield per kg glucose. L-lysine and L-threonine are mainly produced in Europe (Germany, France, Slovakia), the USA and China. Although China may produce most of the L-lysine and L-threonine, we focused on the production in Europe as China is not accessible for information. We found a Dutch consultant who is very familiar with the fermentation production process and was willing to cooperate with us to estimate the environmental impact factors. The carbon source for the production process of L-lysine and L-threonine is glucose. In Europe, corn and wheat are the main raw materials for glucose (Oosterhuis, 2005; Oosterhuis , 2010). We calculated the environmental impact factors using corn as raw material for glucose production. Also tapioca, cane molasses, beet molasses or starch from potato or cassava can be used as carbon source (Hermann, 2003; Oosterhuis, 2005).
For CSL we also considered system expansion as a method to avoid allocation. Therefore it is necessary to define the avoided product and process by marginal analysis. CSL is mainly used as animal feed. Replacing CSL in the average animal feed ratio can be estimated by using linear optimization based on average prices for feed raw materials. This would lead to a multiple replacement of raw materials which are themselves co-products. For instance if CSL is replaced by soy bean meal (both have a crude protein content of approximately 50%) the difficulty arises that also crude soy bean oil is produced as a co-product which needs to be replaced. Moreover the other nutritional values, as for instance starch and sugar content, also differ and that would induce other substitutions. Because of this complexity system expansions has not been applied in this study[3].

2.6.2. *Background data*

For background data, such as the production of components and the production mix of electricity we used figures from the Ecoinvent database (Ecoinvent 2010)

[3] Schmidt et al 2008 proposed a method for system expansions for animal feed based on a economic assessment that barley and soy beans are the most cheapest suppliers of carbohydrates and proteins. But we think that this method is not accurate enough.

3. Amino acid production

3.1. Bio-synthetic amino acids: Lysine and Threonine

L-lysine and L-threonine are produced by a bio-synthetic process where micro-organisms produce the amino acids using glucose as a carbon source (L-lysine and L-threonine are produced with a C-yield of resp. 40% and 35%) and corn steep liquor (CSL) as a source for vitamins and amino acids. Ammonium sulphate is mainly used as source for nitrogen. Raw materials for glucose are coren, wheat, cane molasses or beet molasses. CSL is a co-product of processing corn into starch, corn oil, gluten and sweeteners (Galitsky et al, 2003). In Table 3.1 and 3.2 the raw materials for synthetic production of L-lysine and L-threonine are presented. We focus on corn as raw material for glucose syrup. To produce 1,000 kg glucose syrup, 1,682 kg corn is needed; to produce 1,000 kg CSL, 15,385 kg corn is needed. For Europe it is assumed that the corn is cultivated in France with a yield of 9 tonnes/ha and an input of N-, P-, K-fertilizer of resp. 250 kg N, 60 kg P2O5 and 35 kg K2O per ha.

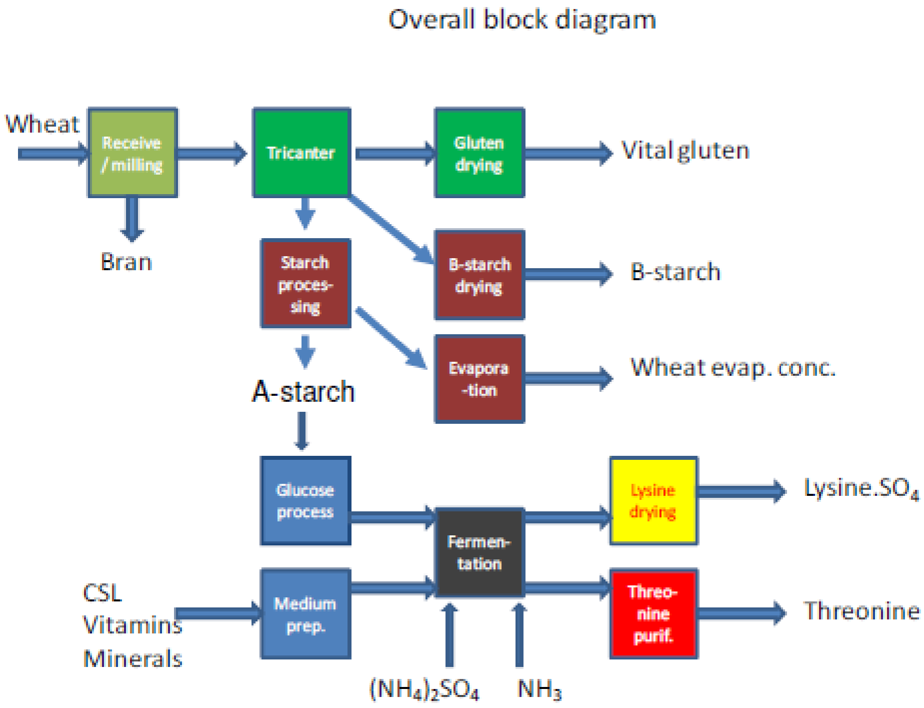

Fig 3.1 A flow diagram of the production of Lysine and Threonine

Table 3.1. Raw materials used for production of 1000 kg L-Lysine (Oosterhuis, 2005 and 2010)

Raw material	unit	Used/ton Lysine[1]
Glucose syrup (as DE98, 70% dry matter)	kg	3500
Corn Steep Liquor (CSL 48%)	kg	300
Ammonia	Kg	155
Ammonium Sulphate	Kg	95
Sulphuric Acid (96%)	kg	320
Phosphoric Acid, 85 % w/w	kg	25
Vitamins, amino acids	kg	4
Salts (like Mg, citric acid, Mn, Fe)	kg	5
Antifoam	liter	10
Process water (fermentation/cleaning)	M3	4.6
Caustic (as 46%) for cleaning	kg	4.5
Nitric acid, 67% for cleaning	kg	1.5

[1] as Lysine.HCL

Table 3.2. The utilities used for production of 1000 kg L-Lysine (Oosterhuis, 2005 and 2010)

Energy source	unit	Used/ton Lysine[1]
Steam fermentation	ton	1.6
Steam evaporation	ton	0.7
Steam evaporation and drying	ton	3.5
Electricity fermentation (incl. cooling/aeration)	kWh	3750
Electricity evaporation and drying	kWh	185
Water for cooling fermentation	M3	7
Water for cooling evaporation	M3	61
Effluent (waste water; low BOD)	M3	4
Total steam consumption	**ton**	**5.8**
Total electricity consumption	**kWh**	**3935**
Total water consumption	**M3**	**72**

[1] as Lysine.HCL

Table 3.3. Raw materials used for production of 1000 kg L-Threonine (Oosterhuis, 2010)

Raw material	unit	Used/ton Threonine
Glucose (100% glucose)	kg	3000
Corn Steep Liquor (CSL 48%)	kg	1000
Ammonia	Kg	700
Sulphuric Acid (96%)	kg	1500
Vitamins, amino acids, salts, antibiotics	kg	5
H3PO4	kg	4
46% Caustic (NaOH) for CIP	kg	200
Down stream processing:		
water	M3	120
Cleaning chemicals	kg	250
resins	liter	300

Table 3.4. The utilities used for production of 1000 kg Threonine (Oosterhuis, 2005 and 2010)

Energy source	unit	Used/ton Threonine
Steam (fermentation, evaporation and drying)	ton	20
Electricity	kWh	12000
Water	M3	9
Downstream utilities (electricity)	kWh	50

3.2. Methionine

D, L-methionine can chemically be produced using raw materials as mentioned in Table 5.

Table 5. The raw materials used for production of 1000 kg Methionine *(EcoInvent??)*

Raw material	unit	Used/ton Methionine
Acrylic acid	kg	376
Methanol	kg	228
Hydrogen Sulfide (H2S)	kg	215
Hydrogen Cyanide	kg	181
Ammonium Carbonaat	kg	1611
Energy source:		
Natural gas	GJ	16

4. Results

4.1. Impact per synthetic component and energy source

The impacts per category for the different synthetic/chemical components are derived from the Ecoinvent database (Ecoinvent 2010) and summarized in Table 4.1 and Table 4.2

Table 4.1 The environmental impacts for the components (per kg) used for L-lysine and L-threonine production (derived from Ecoinvent 2010).

	unit	ammonia	ammonium sulphate	sulfuric acid	phosphoric acid	NaOH
climate change	kg CO2 eq	2,10	0,57	0,12	1,42	0,88
fossil fuel consumption	kg oil eq	0,97	0,21	0,04	0,40	0,23
eutrophication	g P eq	0,19	0,13	0,07	6,56	0,01
acidification	g SO2 eq	5,76	1,62	13,34	33,11	5,85
photochemical smog formation	g NMVOC	3,74	1,24	1,89	6,99	2,37
land use	m2a	0,02	0,02	0,01	0,40	0,00

Table 4.2 The environmental impacts for the components (per kg) used for D,L-methionine production (derived from Ecoinvent 2010).

	unit	acrylic acid	methanol	hydrogen sulphide	hydrogen cyanide	ammonium carbonaat
climate change	kg CO2 eq	2,26	0,80	3,04	0,36	1,55
fossil fuel consumption	kg oil eq	1,45	0,90	1,97	0,19	0,59
eutrophication	g P eq	0,28	0,10	0,32	0,25	0,47
acidification	g SO2 eq	4,36	1,82	16,16	1,38	6,03
photochemical smog formation	g NMVOC	4,86	2,17	6,97	1,12	2,70
land use	m2a	0,02	0,00	0,03	0,02	0,03

The impacts per category from energy used differ between country of production (Table 4.3). The impact for natural gas is including production, transport and burning. The impacts for the categories included in this inventory are significantly lower for France compared to Denmark and Germany. This is because the much higher share of nuclear power in the French production mix of electricity compared to Denmark and Germany. As a consequence the impact on the category 'ionising radiation' is much higher for the French production mix, but this impact category is not included in this inventory.

Table 4.3 The environmental impacts for energy used (per MJ) for amino acid production in the different European countrie (derived from Ecoinvent 2010).

	unit	Germany		Denmark		France	
		electricity	natural gas	electricity	natural gas	electricity	natural gas
climate change	kg CO2 eq	0,18	0,08	0,16	0,07	0,02	0,08
fossil fuel consumption	kg oil eq	0,05	0,06	0,05	0,05	0,01	0,06
eutrophication	g P eq	0,22	0,00	0,05	0,00	0,01	0,00
acidification	g SO2 eq	0,23	0,10	0,36	0,06	0,13	0,08
photochemical smog formation	g NMVOC	0,19	0,12	0,24	0,08	0,08	0,11
land use	m2a	0,003	0,0001	0,007	0,0001	0,001	0,0001

4.2. Impact per biological component

Table 4.4 The calculated environmental impacts for the biological components (per kg) for Lysine and Threonine.

		Corn Steep Liquor	Glucose syrup
climate change	kg CO2 eq	1,54	1,13
fossil fuel consumption	kg oil eq	0,30	0,22
eutrophication	g P eq	0,25	0,18
acidification	g SO2 eq	6,06	4,45
photochemical smog formation	g NMVOC	7,50	5,51
land use	m2a	1,97	1,45

4.3. Impact for amino acid production

Table 4.5. The impact per 1000 kg amino acid produced in three different countries:

Methionine	Unit	**Germany**	**Denmark**	**France**
climate change	kg CO2 eq	5535	5408	5536
fossil fuel consumption	kg oil eq	3073	2983	3042
eutrophication	g P eq	1028	1025	1027
acidification	g SO2 eq	17068	16413	16763
photochemical smog formation	g NMVOC	10353	9717	10128
land use	m2a	69	69	69

Lysine	Unit	**Germany**	**Denmark**	**France**
climate change	kg CO2 eq	8914	8453	6746
fossil fuel consumption	kg oil eq	2809	2689	2187
eutrophication	g P eq	4062	1601	1122
acidification	g SO2 eq	28655	29756	26904
photochemical smog formation	g NMVOC	28043	27926	26201
land use	m2a	5711	5767	5682

Threonine	Unit	**Germany**	**Denmark**	**France**
climate change	kg CO2 eq	19681	18211	13041
fossil fuel consumption	kg oil eq	7551	7143	5632
eutrophication	g P eq	10616	3078	1613
acidification	g SO2 eq	60906	63983	55406
photochemical smog formation	g NMVOC	46236	45589	40494
land use	m2a	6467	6637	6378

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