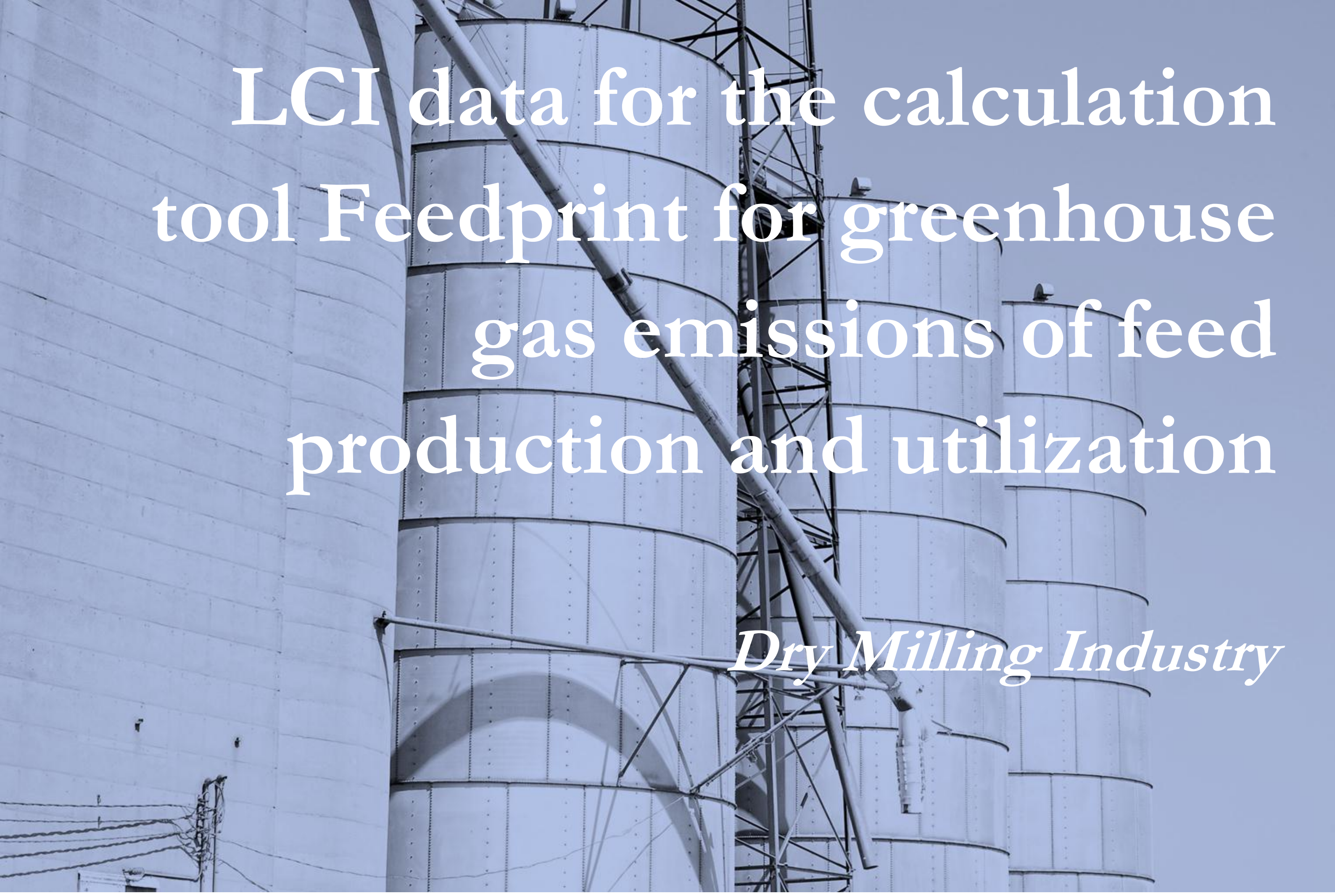

LCI data for the calculation tool Feedprint for greenhouse gas emissions of feed production and utilization

Dry Milling Industry

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November, 2012

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Table of contents

4.1 Introduction

4.1.1 Context of this document & reading guide

This document is part of the background documentation for the FeedPrint program and database. Background information of this project, underlying methodology and justification thereof, can be found in the 'FeedPrint methodology' document. These chapters focus only on the processing step of crops into the feed materials. Information on origin of crops is given, but details on cultivation and transportation (to and from the processing facility) are described in separate documents: the cultivation of each crop is described in the cultivation background reports similar to this one (Marinussen et al, 2012), whereas transportation is described in the Feedprint methodology report (Vellinga et al, 2012).

Each chapter can be read and interpreted as a standalone set of LCI data, which covers the country of crop cultivation, the country of processing, mass balances, energy inputs (and outputs, if applicable), as well as data needed for the allocation of the by-products. In some cases, multiple processes can follow one another with multiple allocation steps. In these cases, the data is entered into the database by following these specific processing steps consecutively. Usually (but not restrictively) the data entered are relative to an input of 1000 kg of crop product.

4.1.2 Overview of products and allocation principles

Each chapter in this document describes a number of dry milling processes, that produce animal feed, mainly as by-product of flour production. The chapters cover animal feed materials derived from dry milling of barley, oat, maize, rice, rye, and wheat. In all of these dry milling processes, one or more by-products for animal feed are produced, with flour usually being the main important product of the processes.

All dry milling processes described in this document are treated as a single unit process with multiple valuable output products, where allocation approach 1 is applied (see §5.3, Vellinga et al, 2012) in which all products are treated as valuable by-products to which upstream emissions will be allocated according to economic, energy, or mass allocation.

4.1.3 Structure of data

This document contains tables that reflect those data applied in the FeedPrint program. Additionally, tables with background data are supplied, which are often inventories of encountered literature. Only the tables that are used as data for the FeedPrint database and calculations are given a table number (see for an example Table 4.1.1). Other tables that are not used in the FeedPrint database are not numbered and have a simpler layout, see the example below.

Table 4.1.1 Example default inputs table for FeedPrint database.

Output	Values		Unit
	Best estimate	Error (σ_g^2)	
Electricity	88	1.4	MJ/ton
Natural gas	245	1.4	MJ/ton

Example of background data not directly used in FeedPrint database

Source	Data found	Remarks
Reference 1	80 MJ/ton	Older data from 1 processing facility.

Reference 2	90 MJ/ton	Newer data from multiple facilities.

There are a number of recurring types of tables, usually in the following order:

1) Definition of feed materials related to the process;
2) Estimation of countries of origin of the crop and countries of processing;
3) Mass balances for the process;
4) Energy or material inputs needed for the process;
5) Allocation factors for the outputs from the process.

Unless explained otherwise in a specific chapter, these five tables are present for each process. Additional sections or figures can give information on, for example, the definition of the process represented with a flowchart. Each section also contains the references for cited sources. The usual structure of a section is that first the default inputs for the FeedPrint database are presented, with the rest of the section explaining in detail which data sources were used and why.

There are a number of different types of error ranges that can be given for each data point, and these are applied for the energy and auxiliary inputs. More background information can be found in the overall methodology document (Vellinga et al. 2012), which also explains the decision process followed to arrive at the error ranges.

4.1.4 Glossary of terms

The number of different by-products from dry milling can become confusing, and some names (like for example husks and hulls) are often used interchangeably. Below is a list of terms with definitions as applied in this document.

Dry milling	A process by which, without adding water, grains are ground up to produce flour an a multitude of byproducts.
Middlings	Generic dry milling by-products, which can represent a number of different parts of the ground grains.
Hulls (or husks)	The other tough skin of the grians, usually rich in fibre.
Germ	The part of the grain from which a new plant can germinate, usually rich in oil and protein.
Bran	The small outer protective layer of the kernel.
Kernel	Denotes the inner part of the grain, when hulls are removed.
Groats	Peeled oat grains.
Crushing	The removal of oil from oil-rich seeds or other kernel components.
DMC	Dry matter content in g/kg.
GE	Gross Energy content in MJ/kg.

4.1.5 References

CVB-table (2012): see appendix 1 in Vellinga et al. (2012)

European Commission. (2011). COMMISSION REGULATION (EU) No 575 / 2011 of 16 June 2011 on the Catalogue of feed materials. Official Journal of the European Union, (L 159), 25–65.

Marinussen et al (2012) Background data documents on cultivation. Blonk Consultants. Gouda, the Netherlands

Vellinga, T.V., Blonk, H., Marinussen, M., van Zeist, W.J., de Boer, I.J.M. (2012) Methodology used in feedprint: a tool quantifying greenhouse gas emissions of feed production and utilization Wageningen UR Livestock Research and Blonk Consultants. Lelystad/Gouda, the Netherlands.

4.2 Dry milling of barley

4.2.1 By-products from dry milling of barley

Barley is milled to decrease particle size and to partly remove the outer hulls. The ingredients listed in the CVB list are by-products from dry milling for the production of pearl barley, which is barley with most of the outer layers (hulls and bran) removed. The product 'Barley mill byproduct' has a higher content of hulls mixed in, but specific compositions were difficult to determine from literature data.

Table 4.2.1 Feed materials from dry milling of barley

CVB	DMC (g/kg)
Barley	869
Barley feed meal high grade	875
Barley mill byproduct	887

Reference: CVB-table (2012)

4.2.2 Sourcing

An estimate of countries that supplies the Dutch feed sources their feed materials is presented in Table 4.2.2. The contribution of these countries may differ considerably through the years, depending on prices and stocks.

Table 4.2.2 Estimated countries of origin of barley

Processing in:	the Netherlands	Belgium	Germany	France
	10%	10%	30%	50%
Crop-country				
the Netherlands	10%	10%		
Belgium	45%	45%		
Germany	30%	30%	100%	
France	5%	5%		100%

4.2.3 Mass balance

Below the mass balance for the dry milling of barley is presented. Since reliable information on the relative amounts (and prices) of by-products produced from milling was not obtained, only a distinction is made between flour (the most important valuable product) and a general category of by-products. The estimate of 35% by-products by weight was based on an FAO document,[1] and corresponds also roughly with other milling fractions found in literature. A relatively large portion of the by-products consists of hulls, which is also reflected in a higher fibre content of the by-products.

Table 4.2.3 Mass balance for dry milling of barley.

Input:	DMC (g/kg)	Mass (kg)
Barley	870	1000
Output:		
Pearled barley	870	650
Dry-milling byproducts	870	350

[1] http://www.fda.gov/ohrms/dockets/dailys/04/nov04/113004/04p-0512-cp00001-03-Appendix-01-vol1.pdf

4.2.4 Inputs dry milling

The energy consumption of the production process is based on information of a number of grain milling examples given in LCAFood (2003), which is used as a default value. As these values (which are listed the same for three grain types) are not based on barley milling itself, a high uncertainty is assumed for the energy inputs.

Table 4.2.4 Energy input for dry milling of barley.

Input	Distribution	Best estimate	Error (σ_g^2)	Unit
Natural gas	Lognormal	360	1.5	MJ/ton barley
Electricity	Lognormal	290	1.5	MJ/ton barley

4.2.5 Allocation

In this section you can find the economic value, gross energy content and mass of each co-product from the dry milling of wheat. The prices are based on 'Barley, pearled' and 'Barley feed flour' from FAOSTAT (averaged over 2005-2008).

Table 4.2.5 Allocation factors of the by-products of barley (CVB codes in parenthesis, if applicable)

Co-product	Mass (kg)	DMC (g/kg)	Price (€/kg)	GE (MJ/kg)
Pearled Barley	650	869	0.86	14.7
Barley feed meal high grade (16800)	350	875	0.51	14.0
Barley mill byproduct (16500)		887		13.6

4.2.6 References

CVB-table (2012): see appendix 1 in Vellinga et al. (2012)

http://beef.osu.edu/library/barley.html

http://www.grains.org/barley

LCAfood (2003): www.lcafood.dk/processes/industry/flourproduction.htm

Vellinga, T.V., Blonk, H., Marinussen, M., van Zeist, W.J., de Boer, I.J.M. (2012) Methodology used in feedprint: a tool quantifying greenhouse gas emissions of feed production and utilization Wageningen UR Livestock Research and Blonk Consultants. Lelystad/Gouda, the Netherlands

4.3 Dry milling of oats

4.3.1 By-products from dry milling of oats

Table 4.3.1 lists the feed materials from dry milling of oats as present in the CVB feed table. Peeled oat grains (groats) are the remainders when the outer husks are removed. Oats mill feed is considered to be a mixture of these two. The definitions of husk and bran are often used interchangeably in the literature sources. Bran is in principle not the same as husk (it refers to the outer layer of the dehusked kernel) but is in general also the name for the general by-product of milling.

Table 4.3.1 Feed materials from dry milling of oat

CVB name	DMC (g/kg)
Oats grain peeled	884
Oats husk meal	907
Oats mill feed meal high grade	886

Reference: CVB-table (2012)

4.3.2 Sourcing

An estimate of countries that supplies the Dutch feed sources their feed materials is presented in Table 4.3.2. The contribution of these countries may differ considerably through the years, depending on prices and stocks.

Table 4.3.2 Estimated countries of origin of oats

Processing in:	the Netherlands	Belgium
	50%	50%
Crop-country		
the Netherlands	75%	25%
Belgium	25%	75%

4.3.3 Mass balance

Below the mass balance for the dry milling of oat is presented. The origin of these values are underpinned in the remainder of this section. Since reliable information on the relative amounts of by-products produced from milling was difficult to obtain, only a distinction is made between flour (the most valuable product) and a general category of husk meal for feed purposes. For the latter category, no detailed price information is available in any case, so allocation cannot be performed at a more detailed level.

Table 4.3.3 Mass balance for dry milling of oat.

Input:	DMC (g/kg)	Mass (kg)
Oat grain	889	1000
Output:		
Peeled oat grains	880	700
Oat husks	910	300

It was difficult to find a detailed mass balance on oats milling, especially for animal feed (for which 75% of all oats is cultivated (see Strychar), LCAfood (A) and W.J. Lim et. al (B) only give very general mass balances, in which they distinguish the weight percentages for two categories: oat flour and out bran. Oat flour is in fact milled peeled oat grain, so the mass balance should be similar whether looking at flour or peeled grains as an output. Bran in these sources indicate the general by-product next to the flour production and is probably higher than only the husks. In processing for human consumption, many by-products are possible (see for example the *Handbook of Postharvest Technology,* edited by A. Chakraverty et al.). As said before a simple mass balance is applied, only distinguishing flour/peeled oat grains and husks . Since the values of LCAfood and Lim et al. are likely on the high side for the product of hulls as defined correctly, the higher end value of NDSU will be applied, with an error margin of ±50. The 30% figure for the hull component is also found in a number of online sources (for example http://www.wittemolen.nl/nl/content/5-1-513/haver.htm).

Inventory of mass balances

Product	DMC (g/kg)	LCAfood (2003)	Lim et al. (1992)	NDSU (1991)
IN:				
Oats	889	1000	1000	1000
OUT:				
Peeled oat grains/flour	900	600	650	760-700
Oat husks/bran	890	400	350	240-300

4.3.4 Inputs

Table 4.3.4 Default energy inputs for dry milling of oat.

Input	Distribution	Min	Max	Unit
Natural gas	Uniform	25	360	MJ/ton oats
		Best estimate	Error (σ_g^2)	
Electricity	Lognormal	290	1.2	MJ/ton oats

The energy consumption of the production process of oat was found in two different sources, see the table below, as well as the references.

Inventory of energy consumption of dry milling of oat.

Source	Parameter	Value
McDevitt et al.	Electricity	0.077 kWh/kg oats
	Diesel	0.0006 kg/kg oats
LCAfood (2003)	Electricity	0.08 kWh/kg
	Natural gas	0.1 kWh/kg

The electricity consumption in case of McDevitt et al. was found to be very similar to LCAfood (2003) and the approximate rounded off values were applied in the final default energy input. The fuel use varies strongly from (using 42.7 MJ/kg for diesel) 25 MJ to 360 MJ per kg oats. Therefore, a uniform distribution between these two values was applied, assuming natural gas as fuel.

4.3.5 Allocation

Table 4.3.5 gives the economic value, gross energy content and mass of each co-product that arises during the processing of oat.

Table 4.3.5 Allocation of the by-products of oat dry milling (CVB codes in parenthesis, if applicable)

Co-product	Mass (kg)	DMC (g/kg)	Price (€/kg)	GE (MJ/kg)
Oats grain peeled (16100)	700	884	0.32	15.9
Oats husk meal (16000)	300	907	0.1	12.7

Prices

The prices are based on general information from Eurostat:

Year	2005	2006	2007	2008	2009	Average
Groats and meal of oats barley and other cereals (euro/kg)	0.22	0.24	0.25	0.50	0.39	0.32

For husks, no general information is found in either FAOstat or Eurostat. However, based on data from Missouri (http://agebb.missouri.edu/dairy/byprod/bplist.asp), the price of husks is estimated to be approximately 30% of the price of meal/flour, so 0.1 euro/kg is applied for oat husk meal.

Mixing of groats and husk

Although no specific information was found on the feed material '*Oats mill feed high grade*', listed in the CVB list, it can be deduced from the composition data that it likely consists of 50% husk and 50% groats. Thus, we assume a final mixing step from these products as described in this report, and no additional energy use for mixing is assumed.

Table 4.3.6 Composition of oats mill feed (CVB codes in parenthesis, if applicable)

	Mass	DMC (g/kg)
Input:		
Oats grain peeled (16100)	500	884
Oats husk meal (16000)	500	907
Output:		
Oats mill feed meal high grade (15600)	1000	886

4.3.6 References

CVB-table (2012): see appendix 1 in Vellinga et al. (2012)

J.E. McDevitt et al., *Life cycle assessment for the ecodesign of UK porridge oat plant varieties*, AgResearch.

LCAfood (2003): www.lcafood.dk/process/industry/flourproduction.htm, authors: A.M. Nielsen and P.H. Nielsen, July 2003.

NDSU (1991). 1991, http://www.ag.ndsu.edu/pubs/ansci/beef/as1020w.htm

Second Edition, ISBN: 978-1-891127-64-9.

Strychar, R, "World Oat Production, Trade, and Usage", Chapter 1 in OATS: Chemistry and Technology

The Handbook of Postharvest Technology – Cereals, Fruits, Vegetables, Tea and Spices, edited by A. Chakraverty et. al., Marcel Dekker, Inc. New York, USA, 2003, Chapter 12 on Specialty Mililng including oats is written by A.K. Sarkar;

Vellinga, T.V., Blonk, H., Marinussen, M., van Zeist, W.J., de Boer, I.J.M. (2012) Methodology used in feedprint: a tool quantifying greenhouse gas emissions of feed production and utilization Wageningen UR Livestock Research and Blonk Consultants. Lelystad/Gouda, the Netherlands

W.J. Lim et al., (1992). *Isolation of Oat Starch from Oat Flour,* Cereal Chem. 69(3):233-236, 1992;

4.4 Dry milling of maize

4.4.1 By-products from dry milling of maize

Table 4.4.1 lists the feed materials from dry milling of maize as present in the CVB feed table.

Table 4.4.1 Feed materials from dry milling of maize

CVB	DMC (g/kg)
Maize feed meal	872
Maize feed flour	881
Maize bran	873
Maize feed meal extracted	868

Reference: CVB-table (2012)

Some small differences exist between these products, but for the LCI they are all considered to be similar products from the dry milling of maize.

4.4.2 Sourcing

An estimate of countries that supplies the Dutch feed sources their feed materials is presented in Table 4.4.2. The contribution of these countries may differ considerably through the years, depending on prices and stocks.

Table 4.4.2 Estimated countries of origin of maize

Processing in:	the Netherlands	USA	Germany	France
percentage	25%	35%	20%	20%
Crop-country				
the Netherlands	0%			
USA	34%	100%	25%	
Germany	33%		50%	
France	33%		25%	100%

Table was constructed using import statistics combined with insight from a milling expert from the Netherlands (personal communication March 2011).

4.4.3 Mass balance

Dry milling is the general process in which cereal grains are ground into flour resulting in several by-products. As mentioned before, we do not have sufficiently detailed data to construct a mass balance for all the listed CVB products, and thus the mass balance below gives a generic by-products amount stemming from maize dry milling, based on Bolade, 2009.

Table 4.4.3 Mass Balance for dry milling of maize.

Input:	DMC (g/kg)	Mass (kg)
Maize grain	872	1000
Output:		
Flour	870	700
By-products	870	300

4.4.4 Inputs

The default input data is presented in Table 4.4.4 below, with further explanation in the remainder of the section.

Table 4.4.4 Energy input for maize dry milling.

Input	Distribution	Best estimate	Error (σ_g^2)	Unit
Natural gas	Lognormal	580	1.4	MJ/ton maize
Electricity	Lognormal	250	1.4	MJ/ton maize

According to Li, Y., Biswas, P., & Ehrhard, R (based on Mei, Dudukovic, Evans, & Carpenter, 2006) the milling step of the ethanol production facility uses 0.21 MJ thermal energy and 0.10 MJ electricity for the production of 1 liter of ethanol. Applying the mass balance presented as 1 kg corn needed for the production of 0.32 kg ethanol (which equals 0.4 liter) and assuming 90% efficiency for the production of thermal heat from natural gas, the default values as presented in the table above are derived. The data might not be representative for the actual dry milling for animal feed purposes, and thus the error margin is considerable.

4.4.5 Allocation

In this section you can find the economic value, gross energy content and mass of each co-product which arises from the dry milling of maize. The flour price is based on generic 'Flour & grit' from FAOSTAT. The feed components by-products' price is based on 'Corn bran/fiber' (averages 2005-2009).

Table 4.4.5 Allocation of the by-products of maize dry milling (CVB codes in parenthesis if applicable)

Co-product	Mass (kg)	DMC (g/kg)	Price (€/kg)	GE (MJ/kg)
Maize flour	700	884	0.6	15.4
Maize feed meal (11700)	300	872	0.2	15.5
Maize feedflour (11600)		881		15.2
Maize bran (11800)		873		14.7
Maize feed meal extracted (13300)		868		14.7

4.4.6 References

Bolade, M. K. (2009) Effect of flour production methods on the yield , physicochemical properties of maize flour and rheological characteristics of a maize-based non- fermented food dumpling *3*, 288–298.

CVB-table (2012): see appendix 1 in Vellinga et al. (2012)

LCAfood (2003): www.lcafood.dk/process/industry/flourproduction.htm, authors: A.M. Nielsen and P.H. Nielsen, July 2003.

Li, Y., Biswas, P., & Ehrhard, R. (n.d.). Energy and Mass Balance Model - Corn dry milling. Washington University. Retrieved from http://www.aerosols.wustl.edu/education/energy/ethanolaudit/index.html

Maize Marketing Center, Maize and Flour Testing Methods: A Guide to Understanding Maize and Flour Quality, Version 2, Kansas State University, September 2008.

Mei, F., Dudukovic, M. P., Evans, M., & Carpenter, C. N. (2006). Mass and Energy balance for a corn-to-ethanol plant. Methods. Washington University, Saint Louis, Missouri.

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4.5 Dry milling of rice

4.5.1 By-products from dry milling of rice

Table 4.5.1 lists the feed materials from dry milling of rice as present in the CVB feed table. Rice with hulls is used as a feed material, and is also the input for the dry milling process described below[2].

Table 4.5.1 Feed materials from dry milling of rice

CVB	DMC (g/kg)
Rice feed meal ASH 0-90 *	897
Rice feed meal ASH >90 *	908
Rice with hulls (=paddy rice)	886
Rice without hulls (=brown rice)	872
Rice husk meal (=husk from paddy rice)	911
Rice branmeal, solvent extracted	899

Reference: CVB-table (2012)

* rice feed meal contain 61% hull, 35% bran and 4% polish; rice bran and polish are by-products of rice milling.

4.5.2 Sourcing

An estimate of countries that supplies the Dutch feed sources their feed materials is presented in Table 4.5.2.. The contribution of these countries may differ considerably through the years, depending on prices and stocks.

Table 4.5.2 Estimated countries of origin of rice

Processing in:	China	India
percentage	65%	35%
Crop-country		
China	100%	
India		100%

4.5.3 Mass balance

Below the Mass balance for the dry milling of rice is presented. The origins of these values are underpinned in the remainder of this section. Rice bran can be further processed to extract oil, which co-produces extruded rice bran meal. This process is treated in a later section of this chapter.

Table 4.5.3 Mass balance for dry milling of rice.

Input:	DMC (g/kg)	Mass (g/kg)
Paddy rice	886	1000
Output:		
Rice husk	910	200
Brown rice:	870	800
Rice bran	910	100
White rice	870	700

There are a number of ways through which rice can be processed, with the main goals being the production of rice for human consumption. As with all dry milling products, a variety of outputs is possible depending on the desired output at that time. Since one of the by-products of interest is rice bran, we here considered only the production of white rice, where the bran has been removed fully.

[2] The paddy rice has, at this stage, already been dried compared to its harvested dry matter content (and this is included in the cultivation section of the inventory).

Brown rice (as listed in the CVB list) is dehulled rice with bran still attached. It is thus considered the combination of bran and white rice for mass balance purposes.

Inventory of mass balances found in literature for the output of dry milling 1000 kg paddy rice.

Sources:	IRRI (2012)	Ekaslip (1995)	Prasara-a (2009)	Blengini (2009)	Kahlon
Rice husk	200	250	230	200	180-200
Rice bran	50-100		90		100-120
Rice without hulls	700		650-700	700	660-700

4.5.4 **Inputs**

Default energy inputs are shown in Table 4.5.4. The remainder of this section underpins these data and also supplies more detailed data on composition of the inputs and output products.

Table 4.5.4 Default input data for rice dry milling.

Input	Min	Max	Unit
natural gas	0	1570	MJ/tonne rice input
electricity from the grid	0	640	MJ/tonne rice input

Dry milling of rice can proceed via a number of routes, including an optional pretreatment step during which the rice is parboiled. This means that the rice is boiled in the husk, which makes subsequent processing easier. The most recent source that we found on direct energy usage is from Blengini and Busto, 2009. According to this study, 277 MJ electricity/tonne rice is used for the dry milling and processing process. Additionally, the parboiling process uses 1570 MJ heat (including the subsequent drying step) and 364 MJ electricity. These data are applied for the feedprint database

Rice husks are an abundant by-product which are often used as an energy source at the rice processing facility. If fully utilized, the energy produced (in the form of both electricity and heat) exceeds the need of dry milling and process and can be exported to external users. This is likely not the case if parboiling is included (see Prasara-a); the production of 90-125 kWh electricity per ton paddy rice indicated seems insufficient to incorporate the parboiling process.

Taking all of the above into account, given the uncertainties of the inclusion of either parboiled rice or the presence of a rice-husk based power supply, the actual energy usage is very uncertain. So, it was decided to take the range of values as a uniform distribution from zero to the maximum amount including the parboiling process.

4.5.5 **Allocation**

This section summarizes the economic value, gross energy content and mass of each co-product which arises during the production process of rice into rice flour. As described above, no distinction is made (relating to energy use) between milling where bran is produced or only brown rice. As a number of different products arise, the allocation is split up accordingly.

Table 4.5.5 Allocation for production of husk meal and brown rice (CVB codes in parenthesis if applicable)

Co-Product	CVB name	Mass (kg)	DMC (g/kg)	Price (€/kg)	GE (MJ/kg)
Brown rice	Rice without hulls (14510)	800	870	0.61	15.2
Rice husk	Rice husk meal (14700)	200	910	0.04	11.6

Table 4.5.6 Allocation for production of rice bran and rice feed meal (CVB codes in parenthesis if applicable)

Co-Product	CVB name	Mass (kg)	DMC (g/kg)	Price (€/kg)*	GE (MJ/kg)
White rice	NA	700	870	0.83	14.9
Rice bran	NA	100	910	0.20	17.5*
Rice husk	NA	200	910	0.04	11.6

* GE of rice bran determined based on mass balance and MJ/kg of brown rice and components.

Prices

The price of brown and white rice were taken from Dutch FAOstat import statistics, averaged over 2005-2009, using the categories of 'Rice husked' and 'Husked/milled rice' respectively. No such data was found for husks but two sources (the Missouri By-product feed price listing and Blengini, 2009) indicate on average around 40 euro per tonne husks: a little over 5% of the price of rice itself.

Composition of rice feed meal

The two rice feed materials are described as containing 61% hull, 35% bran and 4% polish. Polish originates during the same phase as bran removed, and thus the rice feed meal will be adopted as simply the combination of 61% rice husk and 39% rice bran (which comes close to the actual outputs of the process.

Table 4.5.7 Composition of Rice feed meal (CVB codes in parenthesis if applicable)

	Mass	DMC (g/kg)
Input:		
Rice husk	610	910
Rice bran	390	910
Output:		
Rice feed meal ASH 0-90 (17010) Rice feed meal ASH >90 (17020)	1000	910

4.5.6 Rice bran oil production

The processing of bran to rice bran oil and germ meal is a fairly straightforward process where the oil is extracted via a solvent extraction process with hexane. This chrushing process yields the crude oil and rice brain meal.

4.5.7 Rice bran oil production: Mass balance

The mass balance for rice bran oil production is shown in Table 4.5.8.

Table 4.5.8 Mass balance of rice bran oil production (crushing).

Input:	DMC (g/kg)	Fat (g/kg)	Mass (kg)
Rice bran	910	170	1000
Output:			
Rice branmeal, solvent extracted	900	32	860
Rice brain oil	1000	1000	140

Typical oil contents for rice bran varies and according to some sources ranges from 10-23% (IRRI, Rice knowledge bank). A rice brain oil producer[3] lists it as 17% and this will be the starting point for deriving the mass balance..

If the dry matter and oil contents of the oilseed are known, the mass balances can be deduced for oil extraction with an organic solvent. In the final rice bran meal as listed in the CVB list 32 g/kg oil remains. The numbers in Table 4.5.8 are based on this extraction rate starting from 17% oil content in the bran as a starting point. It is equivalent to the extraction of 14% of oil from the bran. As mentioned, there is a considerable uncertainty since the oil yield can widely vary.

4.5.8 Rice bran oil production: Inputs

Since specific data were not found, rapeseed processing is used as a basis of comparison to obtain general oil extraction figures on energy requirements for crushing of germ. These can then be recalculated on the amount of energy required per amount of oil extracted. Table 4.5.9 shows the inputs needed for processing 1 tonne of germ, calculated in this manner. See also the final chapter in the FeedPrint LCI data report on the crushing industry, which deals with generic oilseed processing.

Table 4.5.9 Default inputs for oilseed processing (solvent extraction, for 1 tonne of bran).

Input	Values		Unit	Ref
	Best estimate	Error (σ_g^2)		
Electricity (extraction)	88	1.4	MJ/ton	b
Natural gas (extraction)	245	1.4	MJ/ton	b
Hexane	0.4	1.4	kg/ton	c

b: Based on values from Croezen (2005), Schmidt (2007), and Hamelinck (2008), recalculated relative to oil production.; c: Schmidt (2007)

4.5.9 Rice bran oil production: Allocation

All items on the CVB list, except for the unprocessed germ, are represented in the mass balances and allocation data tables below. Rice bran oil price is derived from Faostat (average prices from 2005 – 2009) while rice bran meal does not have any recent statistics, so a generic category of 'Cake from oilseeds' was applied.

Table 4.5.10 Allocation of the by-products of oil production (CVB codes in parenthesis if applicable)

Co-product	Mass (kg)	DMC (g/kg)	Price (€/kg)	GE (MJ/kg)
Rice branmeal, solvent extracted (15200)	860	900	0.10*	13.0

[3] http://www.thaiedibleoil.com/english/product_process_01.php

Bran oil	140	1000	0.85	37.0

* Price of generic vegetable meal from FAOstat.

4.5.10 References

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CVB-table (2012): see appendix 1 in Vellinga et al. (2012)

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4.6 Dry milling of rye

4.6.1 By-products from dry milling of rye

Table 4.6.1 lists the feed materials from dry milling of rye as present in the CVB feed table.

Table 4.6.1 Feed materials from dry milling of rye

CVB name	DMC
Rye middlings	872 g/kg

Reference: CVB-table (2012)

4.6.2 Sourcing

An estimate of countries that supplies the Dutch feed sources their feed materials is presented in Table 4.6.2. The contribution of these countries may differ considerably through the years, depending on prices and stocks.

Table 4.6.2 Estimated countries of origin of rye

Processing in:	the Netherlands	Belgium	Germany
percentage	80%	10%	10%
Crop-country			
Germany	80%	60%	100%
Poland	20%	20%	
Belgium		20%	

4.6.3 Mass balance

It was difficult to find an extended mass balance on rye milling. LCAfood (A) gives a very general mass balance, but contains only the weight percentages for "rye flour" and "rye bran". The CVB entry of rye middlings is a general category, and bran is often also meant to denote a general by-product. Since the more realistic bran content is much lower (see for example Nilsson, 1997), the value from LCAfood (2003) likely also includes other by-products from milling. It is thus applied in the mass balance as representing the general middling category. For this reason a large error margin will be assumed..

Table 4.6.3 Mass balance for rye dry milling

Product	DMC (g/kg)	Mass (g/kg)
In:		
Rye	872	100
Out:		
Rye flour	872	700
Rye bran/middlings	872	300

References: LCAfood (2003)

4.6.4 Inputs dry milling

The energy consumption of the production process from LCAFood (2003) is used as the default value.

Table 4.6.4 Default energy inputs for dry milling of oat.

Input	Distribution	Best estimate	Error (σ_g^2)	Unit
Natural gas	Lognormal	360	1.2	MJ/ton oats
Electricity	Lognormal	290	1.2	MJ/ton oats

4.6.5 Allocation

This section summarizes the economic value, gross energy content, protein content and mass of each co-product which arises during the processing of rye.

Table 4.6.5 Allocation of the by-products of rye dry milling (CVB codes in parenthesis if applicable)

Co-product	Mass (kg)	DMC (g/kg)	Price (€/kg)	GE (MJ/kg)
Rye flour	700	872	0.43	14.8
Rye middlings (9100)	300	872	0.30	14.1

Prices

Regarding the prices, we were only able to find some very general information from Faostat, using a generic bran category for rye bran/middlings:

Year:	2005	2006	2007	2008	2009	Average
Bran of cereals (euro/kg)	0.20	0.22	0.25	0.32	0.53	0.30
Flour of rye (euro/kg)	0.31	0.30	0.39	0.59	0.58	0.43

4.6.6 References

CVB-table (2012): see appendix 1 in Vellinga et al. (2012)

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4.7 Dry milling of wheat

4.7.1 By-products from dry milling of wheat

Table 4.7.1 lists the feed materials from dry milling of oats as present in the CVB feed table. Depending on the input material, type of processing or desired outputs a range of by-products from dry milling are possible, with varying compositions. Middlings, for example, can consist of a varying mixture of any of the leftovers from dry milling, mostly bran and germ). Since there is a major overlap between these products it was decided to group them for allocation purposes. It is also clear from the data provided in the CVB list that these are very similar products. Besides the categories germ and middlings, feed, bran and flour are produced (but these two ingredients are not included in the CVB list).

Table 4.7.1 Feed materials from dry milling of wheat

Category	CVB	DMC*
Middlings, feed & flour	Wheat middlings	865 g/kg
	Wheat feedflour Crude Fiber<35	865 g/kg
	Wheat feedflour Crude Fiber35-55	869 g/kg
	Wheat feed meal	868 g/kg
Germ	Wheat germ feed	868 g/kg
	Wheat germ	877 g/kg

Reference: CVB-table (2012)

4.7.2 Sourcing

An estimate of countries that supplies the Dutch feed sources their feed materials is presented in Table 4.7.2. The contribution of these countries may differ considerably through the years, depending on prices and stocks.

Table 4.7.2 Estimated countries of origin for wheat

Processing in:	the Netherlands	Belgium	Germany
percentage	80%	10%	10%
Crop-country			
France	35%		
Germany	50%		100%
Denmark	10%		
UK	5%		
Belgium		100%	

This data was constructed using import statistics combined with insight from a milling expert from the Netherlands (personal communication March 2011).

4.7.3 Mass balance

Below the Mass balance for the dry milling of wheat is presented. The origins of these values are underpinned in the remainder of this section.

Table 4.7.3 Mass balance for dry milling of wheat.

Input:	DMC (g/kg)	Mass (kg)
Wheat grain	876	1000
Output:		
Middlings & feed	870	125
Germ	870	20

Wheat bran	870	120
Wheat flour	880	730

In reality, the relative amount of flour produced depends on the specifications of the outcome. If for example a whole grain flour is produced, much of the bran and middlings end up in the flour itself (which would move towards brown flower). It is not uncommon for some types of cereals and/or products to be milled at a 100% rate, so little to no animal feed by-products are produced. We assume here the more general case of milling rates where on average 15-20% animal feed by-products are produced.

We have found two mass balances describing the production process of wheat flour. The first column gives the dry matter content (DMC) of each (by-) product. We have tried to check each mass balance by multiplying the mass of the input and mass of the output by the DMC (g/kg) which gives the dry matter content in kilograms. The DMC (kg) of the input should now be equal to the cumulative DMC (kg) of the output, because in general the DMC (kg) cannot increase or decrease theoretically[4] during this production process. (For specific processes, like anaerobic digestion, this is not the case. Chemical processes can result in bonding to air molecules of releasing molecules into the air, resulting in an unequal mass balance.) To compare the different mass balances, the DMC (kg) of the input is set to 100%, and the weights of the outputs are normalized accordingly. The cumulative share of the output cannot be higher or lower than 100%.

Bechtel et al. (1999) did not give any values for the dry matter content of wheat. We have therefore chosen to use the DMC as stated in the Atlas of nutritional data of United States and Animal feeds (A) and EvaPig (E). These values are all very close to or similar to the dry matter content as given in the CVB list. We therefore assume that the wheat by-products from this production process are therefore similar to the by-products mentioned in the CVB list.

Inventory of mass balances found in literature

Product	DMC	LCAfood (2003)	Bechtel (1999)	DM	%	%Final
IN:						
Wheat grain	87.6	1	1,361,912	1,193,035	100	100
OUT:						
Middlings	86.9		204,287	177,525	15	15
Wheat germ	87.4		27,238	23,806	2.0	2.0
Wheat feed meal	87.9		13,619	11,971	1.0	1.0
Wheat bran	86.6	0.2*	163,429	141,530	12	12
Wheat flour	88	0.8	948,299	834,503	70	70

* Bran including other outputs.

We found only one extensive mass balance in Bechtel et al. (1999), but several other references fit these results. Wheat consists of 2.5% germ and 14.5% bran according to the Handbook of Postharvest Technology. When we compare these percentages to the mass balance of Bechtel et al. we see that the amount of germ is equal to approximately 2% and the amount of bran is equal to 12%. These values are slightly lower than the ones stated in the Handbook of Postharvest Technology, but that could be due to the fact that part of the bran and germ ends up as middlings (which is a varying mixture of these two ingredients). Also the information from LCAfood (2003), which shows a very general mass balance of 80% wheat flour and 20% wheat bran (including other by-products) corresponds with this result, although the grinding percentage is higher. According to a milling expert of Meneba, by far the largest

4 Also in a dry process there are very small losses in the process, such as dust forming and remainders at machinery. These losses are in practice much smaller than 1%.

mill in the Netherlands, the grinding percentages of wheat are usually around 72-75% for wheat, which is slightly higher than the results of Bechtel et al (1999). However, as Bechtel et al (1999) is the only source with a very complete data set, this source will be used for the default mass balance, but adjusted to a higher flour yield at 73% (which is compensated by a decrease in middlings & feed yield).

4.7.4 Flowchart

The production process of wheat flour can be found in Figure 4.7.1. Wheat arrives at the milling company and is first screened and cleaned, than the wheat kernels go through a shifter and a purifier and are rolled to produce wheat flour. The final shifter distinguishes wheat flour and different kind of by-products (which are suitable for the feed industry).

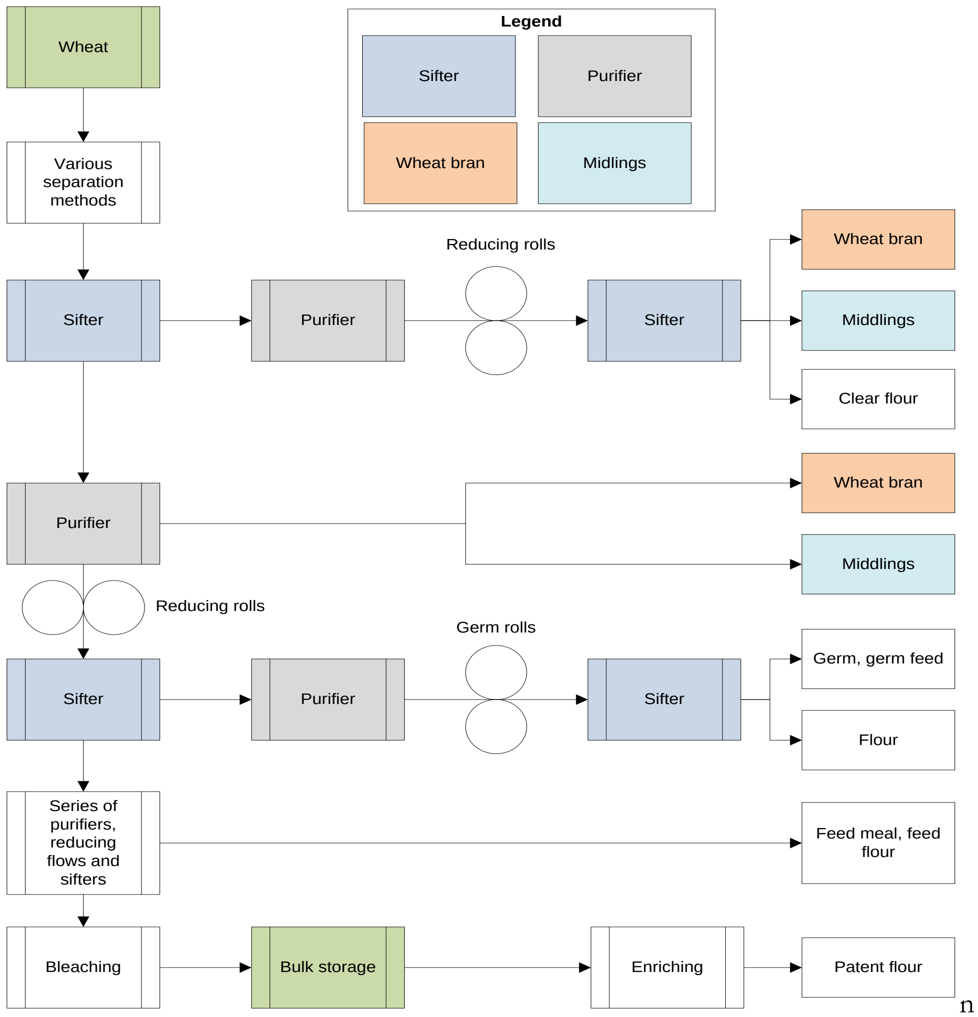

Figure 4.7.1: Flowchart of dry milling of wheat, reference: Wheat Marketing Center, Wheat and Flour Testing Methods: A Guide to Understanding Wheat and Flour Quality, Version 2, Kansas State University, September 2008. (I)

4.7.5 Inputs

Default energy inputs are found in the table below. The remainder of this section underpins these data and also supplies more detailed data on composition of the inputs and output products. One source was used for the default data, which is representative for Dutch industry, and for which a 10% error margin is appropriate. For other countries, the error margin is assumed to be 20%.

Table 4.7.4 Default input data for wheat dry milling.

Input	Distribution	Best estimate	Error (σ_g^2) (Dutch industry / Other)	Unit
Natural gas	Lognormal	174	1.1 / 1.2	MJ/ton wheat
Electricity	Lognormal	290	1.1 / 1.2	MJ/ton wheat

The energy consumption of the production of wheat flour from wheat was found in three different sources, see the table below.

Energy consumption of dry milling, energy inputs per tonne of wheat as input.

Source	Parameter	Inventory	Input / tonne wheat
Espinoza-Orias et al. (2011) PAS [a]	Electricity	0.048 kWh/loaf*	88 kWh
Espinoza-Orias et al. (2011) Generic [a]	Electricity	0.107 kWh/loaf*	197 kWh
		Average:	142 kWh
van Eijk & van Koot (2005)	Electricity	120,045,292 kWh/1,500,000 ton grains	80 kWh
	Natural gas	7,499,839 m3/1,500,000 ton grains	158 MJ
LCAfood (2003)	Electricity	0.08 kWh/kg	80 kWh
	Natural gas	0.1 kWh/kg	360 MJ

We assumed that one loaf weights around 800 grams, and for one loaf you need 680 grams wheat flour.

*Although the energy consumption is expressed in kWh per *loaf*, the amount of electricity is specified for the energy consumption only during milling.

[a] Espinoz-Orias et al. (2011) approached the data –gathering in two ways: one specifically for the PAS 2050, and one generic.

Data was obtained from a number of public reports and scientific publications. This has been combined with information provided by an expert of the Dutch milling industry. The PAS study in the article of Espinoza is very similar to the electricity use in van Eijk & van Koot (2005) and LCAfood (2203). (Espinoza-Orias et al. (2011) cites LCAfood (2003).) But a lot of assumptions have been made to arrive at this result. In this report we have chosen to adopt the data from van Eijk & van Koot (2005) report as the best estimate for Dutch industry, with a higher error margin for processing in other countries.

This section summarizes the economic value, gross energy content, protein content and mass of each co-product which arises during the production process of wheat into wheat flour.

Table 4.7.5 Allocation of the by-products of wheat dry milling (CVB codes in parenthesis if applicable)

Co-Product	CVB name	Mass (kg)	DMC (g/kg)	Price (€/kg)	GE (MJ/kg)
Wheat flour	NA	730	880	2.737	14.5
Wheat bran	NA	125	870	1.248	16.6
Middlings, feed & flour	Wheat middlings (20600) Wheat feedflour Crude Fiber<35 (20410) Wheat feedflour Crude Fiber35-55 (20420) Wheat feed meal (20500)	120	870	1.248	12.5
Germ	Wheat germ feed (20800) Wheat germ (20300)	20	870	3.80	17.2

Prices

In order to allocate to by-products according to their economic value, we need to know the prices of each co-product. So far we have only found the prices for wheat middlings pellets (in Dutch: *tarwegriespellets*).

Prices of by-products.

Year	2007	2008	2009	2010	2011*	Average
Wheat middlings pellets (euro/ton)	156.2	150.2	94.45	128.4	173.2	140.5

Reference: BINternet (2008) *Average over January – April.

Furthermore we have some values from Schothorst (2011) and Eurostat:

Year	2004	2005	2006	2007	2008	2009	Average
Wheat (euro/100 kg)							15.87
Wheat middlings (euro/100 kg)							12.48
Wheat germ feed (euro/100 kg)							38.00
Wheat or meslin flour (euro/100 kg)	22.97	20.68	22.46	33.22	35.54	29.35	27.37
Groats and meal of common wheat and spelt (euro/100 kg)	16.50	23.10	23.75	26.27	28.29	21.30	23.20

Reference: Wheat, Wheat middlings and Wheat germ feed from Schothorst.xlsx available at Blonk Consultants and Wheat or meslin flour and groats and meal of common wheat and spelt from Eurostat.

It is assumed that wheat germ and wheat germ feed have the same economic value and that the price of wheat feed is similar to `groats and meal of common wheat and spelt´, as well as wheat feed flour. The price of wheat bran is assumed to be similar to wheat middlings, as they are derived from a similar phase during the milling process. Until more information on prices becomes available, it will be assumed that flour is worth twice as much as each co-product.

4.7.6 **References**

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