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Environmental Assessment of the Life Cycle of Bovine Compound Feeds from a Feed Milling Plant in a Large Commercial Farm in Wielkopolska Region, Poland

Abstract. In recent years, the importance of environmental threats associated with intensive livestock production has been emphasized. Compound feeds make up a part of the animal production chain. A complete assessment of the animal production system with regard to environmental criteria is therefore impossible without considering the environmental consequences of feed production. The goal of this research is to fill the gap in an environmental assessment of production processes of compound feeds in Poland. The study presents an assessment of production impacts of bovine compound feeds according to Life Cycle Analysis (LCA) methodology. The data for analysis were based on the set of information obtained from the feed milling plant located in a commercial agricultural enterprise in the Wielkopolska region in the years 2015-2016. An inventory table of inputs was prepared in relation to the functional unit of 1 ton of compound feeds and two phases of production processes, i.e. upstream and core. For average compound feed, the impact category indicators for the global warming potential, acidification, eutrophication, photochemical ozone formation, consumption of mineral resources, fossil fuel resources and the emission of the respirable particles were respectively: 605.9 kg CO_2 eq, 8.73 kg SO_2 eq, 3.32 kg PO_4 eq, 0.73 kg ethylene eq, $3.4x10^{-3}$ kg antimony eq, 5141.1 MJ and 2.25 kg PM2.5 eq. The upstream phase had the greatest effect on investigated impacts, while the core processes phase had a relatively low impact on environmental threats. It is recommended to broaden the scope of the research for a larger group of feed milling plants with more complex manufacturing processes, with a more branched supply structure and a wide range of compound feeds for different animal types. The obtained data can be a valuable source base in prospective analyses of the life cycle of various animal products in Poland.

Key words: environment, life cycle analysis, impact category indicator, compound feed, feed mill, Poland

JEL Classification: Q54, Q57

Introduction

As a consequence of dietary changes based on a higher share of protein and animal fat in the diet of inhabitants of developed countries, as well as world population growth, animal production (especially cattle, pigs and poultry) is developing rapidly following the growing demand for meat products (Steinfeld et al. 2006; FAO, 2006). Compound feeds are a decisive factor for determining high-yield and cost-effective animal production. A steady increase in the productivity of cattle and swine herds for many years is possible due to the use of industrial feed compounds (Jamroz and Potkański, 2001). The production of compound feeds

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in Poland increased from around 8 million tons to over 10 million tons in the years 2010-2016. The entire EU currently produces 156 million tons per year of all types of compound feeds (FEFAC 2018). The growth rate of compound feeds produced in Poland was several times higher than in the EU during this period (27.7% vs. 4.6%). The growing demand for industrial feeds is also favored by increased concentration of animal production units that is necessary to maintain farm profitability and maintain the competitive production of animal products. Feeding with complementary feed compounds enables effective supply of energy and protein to animals. Farms' own fodders (including roughage and cereals) do not contain sufficient amounts of ingredients and energy to cover the needs of animals, in conditions of intensive fattening of animals or high milk-yielding cows. Feedstuffs currently produced are characterized by a complex composition (Kujawiak, 1994). In addition to cereals, they contain most often by-products of the oil, milling and spirits industries, as well as other components like vitamins, minerals (macro and micro elements) or amino acids.

The feed production system is an important part of the livestock production chain. Supply chains are strongly diversified due to the variety of feed sources and production capacities of the feed milling plants. The feed sector is confronted by a wide range of environmental issues among which reducing greenhouse gas emissions is an important priority, in addition to maintaining the competitiveness of production (Coffey et al., 2016). The roughages and compound feeds make a significant contribution to various environmental effects related to the animal production. It is estimated that the feed production makes up approximately 45% of the livestock's carbon footprint worldwide (Gerber et al., 2013). Besides their considerable impact on the greenhouse gas emissions, feed also contributes to other environmental impacts such as eutrophication, acidification, non-renewable energy use and mineral resource use (Binder, 2017).

The production of feed next to animal husbandry is a basic part of the production chain, which significantly affects various types of ecological footprints of animal products. Knowing the final effects of animal production thus requires analysis of environmental impacts in many parts of the food production chain (production of feed, breeding, distribution of livestock and milk, processing, packaging, product distribution and retail sales). The need to conduct environmental assessments of feed production has been underlined in the European initiative on the creation of environmental footprint declarations, known as Product Environmental Footprint (PEF), by including the feed industry to create a pan-European network for creating inventory databases for various product groups (European Commission 2018). Currently, a comprehensive analysis of environmental impacts of the production of compound feeds in Poland is hindered because no complete database of feed production processes has been developed so far with wide-ranging data from the feed industry and on-farm crop production. To date, only environmental assessments of agricultural production for single plant crops, embracing field production and industrial application for bioenergy have been presented in Poland. The goal of the current study is to fill the gap in an environmental assessment of production processes of compound feeds in Poland. The main objective of the research was to assess the environmental effects of compound feed production for cattle according to Life Cycle Analysis (LCA) methodology. Additional objectives were: a) a comparison of the differences in environmental impacts between different types of compound feeds, and b) the determination of the importance of the raw material production stage and the feed manufacturing processes in terms of final indicator results for environmental impact categories in the whole system of compound feed production.

Materials and methods

The research was carried out in a feed mill owned by the agricultural enterprise Długie Stare Sp. z o. o. in the years 2015-2016. The enterprise manages an area of 3240 ha, including 3120 ha of agricultural land. It is among a small group of agricultural enterprises owned by the State Treasury responsible for the implementation and dissemination of technological progress in agriculture. It specializes mainly in the production of milk and beef livestock. The company consists of four farms with an area of 400-600 ha and the feed mill. Currently, the company has 2 000 Holstein-Friesian (HF) cattle, including 900 milk cows. The company also owns a beef cattle farm containing, at present, 473 beef cattle with 200 suckler cows. In crop production, the enterprise activity is focused on the cultivation of cereals, winter rapeseed and sugar beet. Most of the compound feeds used for the cattle come from their own feed milling plant. This produces compound feeds for various cattle categories, that are fed to cattle entirely within the enterprise. The average annual production of compound feeds is 1874 tons. The feed mill is also used for drying cereals and rapeseeds for sale. Annually, about 6700 tons of cereals and rapeseeds are dried. The plant was built in the 1980s but has been modernized several times since. After being brought to the feed mill the grain is cleaned and then directed for drying. Thereafter the portion of grain which is intended for feed material is stored in steel bins. At the stage of preparing feed mixtures, coarse granular components are ground in a mill and then mixed with other ingredients in the mixer in proportions appropriate for the type of compound feed desired. The compound feeds produced are of the loose type. No expansion, extrusion or granulation processes are carried out in the mixing room. In accordance with the needs reported by cattle farms, the feed mill produces compound feeds with a different composition, adjusted to the cattle groups and the physiological condition of dairy cows. During the study, this feed milling plant produced six types of compound feeds used as a complementary feedstuff in the fed diet: CJ - for breeding heifers, B - for young beef cattle, DC - for dairy cows in general, LCC - for lactating dairy cows, DRC- for dairy cows during drying, and GG – ground grain. The detailed composition of compound feeds is shown in Table 1.

The feed blend consists of four groups of ingredients. The first dominant group is cereals. The proportion of cereals varies from 44.5% in the DC to 100% in the GG. In the second group, there are seeds of oilseed crops, i.e. winter rape and soybean. The amount of seeds of this group is in the range 0 to over 41%. By-products of the oil industry, which are represented by rapeseed meal and soybean meal, constitute a maximum 50% of the total feed weight. The remaining part of the compound feed is supplemented by mineral salts and premixes. The largest share of mineral additives in its composition was found in B feed (18%). The feed composition was arranged in cooperation with external specialists in the field of animal nutrition, after chemical analysis for a number of chemical components and their energy value. The chemical composition and nutritional value of the produced compound feeds are presented in Table 2. As is seen in this table, the mixtures produced differed in terms of energy and nutrient contents. Optimization of the composition of those mixtures considered the diversity of animal requirements for nutrients resulting from different directions of utilization, age and production intensity.

Table 1. Supplementary compound feed composition according to mass proportion of ingredients (% as fed) in different types of feeds produced in the feed mill

Supplement ingredient	DM[1] %	Type of supplementary compound feed					
		CJ[2]	B[3]	DC[4]	LCC[5]	DRC[6]	GG[7]
Winter wheat	86.5	30.0					7.0
Winter rye	86.5	20.0				3.3	
Winter barley	86.5	8.0		10.5	1.2		10.0
Triticale	86.5	12.0	77.0	26.0	22.5	13.3	82.0
Grain maize	88.0			8.0	25.0	33.3	1.0
Winter rapeseed	89.9				25.0	16.7	
Soybean	90.0				16.3	16.7	
Rape meal	88.7	10.0	5.0	35.0			
Soybean meal	87.6	16.0		15.0			
Mineral premix – Alamo Perfect	99.0	3.5	5.0				
Mineral premix – Trans I	99.0				10.0		
Mineral premix – Trans II	99.0					16.7	
Calcium carbonate	99.0	0.5	5.0	4.0			
Magnesium oxide	99.0			0.5			
Sodium bicarbonate	99.0		5.0	1.0			
Sodium chloride	99.0		3.0				

[1]DM – dry matter, [2]CJ – compound feed for breeding heifers, [3]B – for young beef cattle, [4]DC – for dairy cows in general, [5]LCC – for lactating dairy cows, [6]DRC – for dairy cows during dry period, [7]GG – ground grain mixture

Source: own calculations

Table 2. Chemical composition and energy value of different supplementary compound feeds produced in the feed mill

Compound feed	DM %	Fat %	Crude protein %	NEL[1] MJ/kg DM	ME[2] MJ/kg DM	DE[3] MJ[4]/kg DM
CJ	87.5	1.88	20.67	7.51	12.96	14.61
B	88.9	1.40	11.70	6.33	11.02	12.40
DC	88.4	2.25	26.67	7.17	12.33	13.96
LCC	89.2	15.18	17.10	8.96	15.39	16.90
DRC	89.9	12.05	15.34	8.08	13.90	15.29
GG	86.5	1.80	12.85	8.01	13.98	15.71

[1]NEL – net energy available for milk production, [2]ME – metabolizable energy, [3]DE – digestible energy, [4]MJ - megajoule

Source: authors' own calculations

Data for analysis came from source documentation of the feed milling plant and from farms of this enterprise. Data collection was carried out by using registration forms. The primary source of information was documents of stock control, physical records of crop farming and feed mill activities, and technical documentation on machines and vehicles. Raw materials consumption, purchase of agricultural production inputs and technical materials for production in the feed mill were recorded using accounting documents, including purchase invoices. An additional source of information was interviews with the managers of the feed mill and farms. The involvement of vehicles and agricultural machinery in different operations in the feed mill and in the farms was assessed on the basis of data on the working time of vehicles and machines and their efficiency in performing various types of technological processes. In field crops, the data collected included all inputs, including, among others: seed, fertilizers, plant protection chemicals, diesel oil, engine oils, lubricants, electricity and detailed characteristics of used vehicles and agricultural machinery.

In addition to the collection of data related to grown crops which were the raw materials for the production of compound feeds, a comprehensive data template for the feed mill was developed. Detailed data on the quantity of cereals and rapeseeds acquired internally from farms as well as other purchased products were obtained. Places of material production, types of transport and transport distances were registered. Monthly and annual consumption of electricity and liquefied petroleum gas (LPG) were determined. Grain moisture content was recorded before and after drying. Existing records of drying characteristics in the feed mill provided data on the duration of this process and the consumption of LPG needed to dry 1 ton of grain of various types of cereals and rapeseeds. Sets of machinery and vehicles participating in internal works in the feed mill (cleaning, transport, collecting materials from storehouse and delivery to the place of their processing) were also analyzed. It was important to have information on the operational data of these vehicles, annual consumption of fuels and lubricants, and the time of their involvement in various operations in the feed mill.

The study was performed according to LCA methodology which follows a specific sequence of steps, taking into account four phases: a) defining the purpose and scope of research, functional unit as well as system boundaries, b) determining the life cycle inventory data, c) assessing the impact of the life cycle of the product, and d) interpretation (Brentrup et al., 2004). The scope of the research included analysis of production processes in the feed mill and in the objects that were the source of raw materials and manufactured inputs. The process of transporting grain from farm fields and materials from outside sources fell within the scope of the present study. Availability of many types of source data and different characterization models, used to convert emissions and resources from inventory to common impact units, allowed estimation of many categories of environmental problems associated with the production of compound feeds. The study of the feed production impacts was characterized by a high degree of specificity because it was related to each product separately. After aggregating the unit processes of all types of feeds being produced, the environmental effect of so called 'average compound feed' (ACF) was also assessed. Results from the case study concern the feed mill which operates in close proximity to the land base of crops needed as raw material inputs for the feed production and being close to farms as places of feed distribution. The proximity of the sources of raw materials minimizes transport distances, compared to feed mills operating as independent commercial units that have many recipients in the market.

Due to the analysis of the entire assortment of compound feeds, functional units equal to 1 ton (t) for each type of feed were chosen. After averaging data for production processes, a functional unit corresponding to 1 t of the ACF was additionally presented. The analysis was carried out in life cycle stages from cradle to gate of the feed mill. This means that in the research, different processes for manufacturing means of production, crop cultivation, industrial production processes of feed components (mineral salts, premixes, vitamins, mineral micronutrients), by-products of the oil industry, transport and processes inside the feed plant had to be included (Fig. 1).

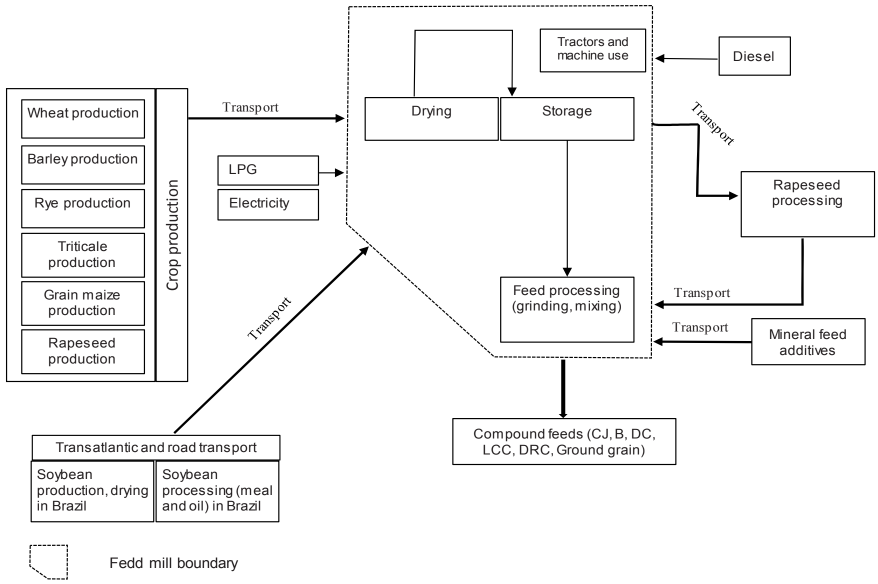

Fig. 1. Description of the compound feed production system in the analyzed feed mill

Source: authors' own description.

The production of compound feed is a complex process with a branched-tree structure. This is manifested by the fact that effects of the initial processes flow into the subsequent processes, and these in turn are components of the next level of transforming processes into final products. Background data for the individual unit processes embracing fertilizers, plant protection products, soybean, fuel and energy production, machines and vehicles, minerals and vitamins came from Ecoinvent (2018) and Agribalyse® databases (Colomb et al., 2013). Inventory of inputs for the rape meal production in the oil mill was developed using literature data (Van Zeist et al., 2012). A model raw material for the oil mill products was winter rape grown in the Długie Stare enterprise, while the route used to transport soybean meal corresponded to the distance between the enterprise and the oil mill in Szamotuły (Wielkopolska voivodship).

In assessing the environmental effects of the life cycle of the compound feeds (LCIA phase), the CML method based on the midpoint approach was applied (Guinèe et al., 2002). The selection of categories and category indicators is of crucial importance and is dependent on the type of threats induced by a given activity. An obligatory part of this method is also classification and characterization. The research covered the following impact categories: global warming potential (GWP), eutrophication potential (EP), acidity potential (AP), photochemical ozone creation potential (POCP), abiotic depletion potential for minerals (ADP minerals), abiotic depletion potential for fossil fuel (ADP fossil), and particulate matter pollution potential (PMP[3]). The analysis of effects for the PMP category was performed using the ILCD 2011 method (Hauschild et al. 2013). Impact values for the analyzed categories were calculated according to the formula:

$$I_{cat} = \sum (m_i \ x \ CF_{cat,i}),$$

where: Icat - indicator of impact category, m - mass of the emitted or used substance "i", CFcat, i - characterization factor of the impact category for a given substance. The measures of the categories are quantifiable indicators, which are expressed in equivalent (eq) units. The reference units for the categories GWP, EP, AP, POCP, ADP minerals, ADP fossil and PMP were, respectively, kg CO_2 eq, kg PO_4 eq, kg SO_2 eq, kg ethylene (C_2H_4) eq, kg antimony (Sb) eq, MJ and kg PM2.5 eq. In order to establish the relationship between the substances emitted and their effects in the environment, appropriate characterization factors were applied based on the characterization models corresponding to the analyzed impact categories. The calculation of category indicators was carried out using the SimaPro software program (Pré Consultants, 2017).

Field crop production and arable crop processing (in the oil and milling industry), apart from the main product, also produce additional commercial effects described as co-products. Therefore, it was necessary to distribute inputs and emissions between the main products and the co-products. The method of economic allocation, based on the value of the products, was chosen as a way of proportional distribution of environmental burdens. According to the LCA methodology, the allocation of emissions was carried out between a range of products in the following proportions: cereals/straw - 0.91/0.09, rape meal/rapeseed oil - 0.27/0.73, soybean meal/soybean oil - 0.62/0.38, cereal flour/cereal bran - 0.91 / 0.09.

Results and Discussion

An important step in the LCA methodology was to develop the inventory database consisting of a set of elementary, intermediate and reference flows of the activity. In Table 3, all major material flow streams are presented in relation to the functional units.

Two stages of the life cycle, namely upstream and core processes, were distinguished within the production system. In upstream processes, material inputs related to fertilization, sowing, plant protection and crop cultivation were included. This stage also involves the consumption of electricity, fuels and materials related to both technological operations in a crop field, as well as in producing material inputs used as components in production of compound feeds. Core processes concerned technological operations directly related to the operation of the feed mill. The main group of entries was the consumption of all material inputs as well as electricity, heat and fuels consumed in technological operations of the feed mill. Transport of compound feed components was also included in this stage. Four categories of transport were distinguished: truck, rail, barge and ocean. The variety of

[3] determined for particles less than or equal to 10 µm

means of transport was to a large extent the result of the adopted transport model of soybean that was imported from Brazil. In the Brazilian soybean transport system, a network of roads, rivers and railways is used (Salin 2017). The Brazilian ports of Rio Grande and Santos, and Świnoujście in Poland were chosen as hubs for soybean transport. The distance of transport between the ports was about 14 644 km. From the port of Świnoujście the soybeans were then transported by trucks with a gross vehicle weight over 32 t, a distance of 372 km to the feed mill.

Table 3. Inventory data for the inputs for the different types of feeds produced in the feed mill with upstream and downstream processes referred to the functional unit

Inputs	Compound feed types								
	CJ			B			DC		
	Upstream	Core	Total	Upstream	Core	Total	Upstream	Core	Total
Fertilizers, kg									
N	22.70	-	22.70	23.56	-	23.56	21.04	-	21.04
P_2O_5	6.90	-	6.90	3.52	-	3.52	5.92	-	5.92
K_2O	12.70	-	12.70	11.29	-	11.29	15.27	-	15.27
Organic fertilizer, kg	52.20	-	52.20	0	-	0	352.87		352.87
Pesticides, kg	1.40	-	1.40	0.22	-	0.22	1.25	-	1.25
Seeds (total), kg	18.18	-	18.18	24.61	-	24.61	12.43	-	12.43
Lime (CaO), kg	62.73	-	62.73	45.60	-	45.60	52.98	-	52.98
Tractors & agric. machinery, kg	3.76	0.02	3.78	3.43	0.03	3.46	3.94	0.02	3.96
Diesel oil (by tractors & machinery), kg	13.30	0.19	13.49	11.09	0.20	11.29	12.57	0.18	12.75
Lubricating oil, kg	0.40	<0.01	0.40	0.45	<0.01	0.45	0.37	<0.01	0.37
Electricity, MJ	85.73	51.53	137.26	10.97	52.67	63.64	100.89	51.57	152.46
Heat, MJ	174.98	0	174.98	2.55	0	2.55	163.20	0	163.20
Hexane,kg	0.76	0	0.76	0.25	0	0.25	2.00	0	2.00
Natural gas, MJ	75.61	0.30	75.91	32.92	0.33	33.25	160.67	0.26	160.93
LPG, kg	0.23	1.11	1.34	0.12	1.38	1.50	0.81	2.40	3.21
Mineral supplements, kg	40.00	0	40.00	180.00	0	180.00	55.00	0	55.00
Steel, kg	0.07	0.36	0.43	0.08	0.46	0.54	0.13	0.27	0.40
Concrete, dm^3	0.31	0.12	0.43	0.25	0.13	0.38	0.14	<0.01	0.14
Transport, tkm	192.0	2418.3	2610.3	3.9	11.2	15.1	195.2	2298.3	2493.5
Lorry	117.7	75.3	193.0	3.9	11.2	15.1	125.5	101.7	227.2
Train	48.4	0	48.4	0	0	0	45.4	0	45.4
Barge	25.9	0	25.9	0	0	0	24.3	0	24.3
Transoceanic	0	2343.0	2343.0	0	0	0	0	2196.6	2196.6

Table 3. Inventory data for the inputs for the different types of feeds produced in the feed mill with upstream and downstream processes referred to the functional unit (cont.)

Inputs	Compound feed type								
	LCC			DRC			Ground grain		
	Upstream	Core	Total	Upstream	Core	Total	Upstream	Core	Total
Fertilizers, kg									
N	24.19	-	24.19	16.59	-	16.59	27.57	-	27.57
P_2O_5	7.56	-	7.56	6.62	-	6.62	4.20	-	4.20
K_2O	19.44	-	19.44	14.74	-	14.74	12.44	-	12.44
Organic fertilizer, kg	1020.65	-	1020.65	1338.99	-	1338.99	38.00	-	38.00
Pesticides, kg	1.78	-	1.78	1.74	-	1.74	0.28	-	0.28
Seeds (total), kg	11.06	-	11.06	9.12	-	9.12	29.50	-	29.50
Lime (CaO), kg	68.82	-	68.82	61.89	-	61.89	53.84	-	53.84
Tractors & agric. machinery, kg	5.17	0.05	5.22	4.38	0.04	4.42	4.19	0.03	4.22
Diesel oil (by tractors & machinery), kg	16.28	0.30	16.58	14.52	0.29	14.81	12.93	0.22	13.15
Lubricating oil, kg	0.49	0.01	0.50	0.44	0.01	0.45	0.51	<0.01	0.51
Electricity, MJ	68.07	0	68.07	77.81	66.19	144.00	0	55.64	55.64
Heat, MJ	32.58	0.02	32.60	69.96	0	69.96	0.17	0	0.17
Hexane, kg	0	0	0	0	0	0	0	0	0
Natural gas, MJ	57.12	0.61	57.73	68.44	0.65	69.09	6.16	0.43	6.59
LPG, kg	0	7.71	7.71	0	9.21	9.21	0	1.84	1.84
Mineral supplements, kg	100.00	0	100.00	166.70	0	166.70	0	0	0
Steel, kg	0.24	0.44	0.68	0.34	0.40	0.74	0.01	0.59	0.60
Concrete, dm^3	0.65	0.43	1.08	0.96	0.11	1.07	0.02	0.17	0.19
Transport, tkm	241.6	2445.0	2686.5	247.5	2445.0	2692.5	1.0	4.2	5.2
Lorry	146.3	65.3	211.6	149.8	65.3	215.1	1.0	4.2	5.2
Train	61.3	0	61.3	62.9	0	62.9	0	0	0
Barge	34.0	0	34.0	34.8	0	34.8	0	0	0
Transoceanic	0	2379.7	2379.7	0	2379.7	2379.7	0	0	0

Source: authors' own calculations.

A comprehensive analysis of environmental effects of the production of compound feeds according to the LCA methodology showed marked differences between the analyzed types of feeds. The LCC mixture was characterized by the highest impacts, except for the POCP and ADP minerals categories (Table 4).

Table 4. Impact category indicators of the feed produced in the feed mill per functional unit (1 t) of each feed type

Impact category indicator	Compound feed type						
	CJ	B	DC	LCC	DRC	ACF[1]	GG
GWP, kg CO_2 eq	611.50	522.50	585.50	729.60	686.60	605.90	533.30
AP, kg SO_2 eq	8.19	8.13	8.29	11.75	11.30	8.73	8.87
EP, kg PO_4 eq	3.35	2.94	3.07	4.25	4.14	3.32	3.27
POCP, kg C_2H_4 eq	0.50	0.23	1.09	0.17	0.18	0.73	0.09
ADP minerals, kg Sb eq	3.3×10^{-3}	4.2×10^{-3}	2.8×10^{-3}	4.9×10^{-3}	5.3×10^{-3}	3.4×10^{-3}	2.7×10^{-3}
ADP fossil, MJ	4882.30	3976.10	5130.10	6441.70	6424.60	5141.10	3774.80
PMP, kg PM2.5 eq	2.12	2.02	2.13	3.01	2.95	2.25	2.12

[1]ACF – average compound feed

Source: authors' own calculations.

The production of DC and CJ feed mixtures and the ACF had the largest impact on the POCP category. In general, feed mixtures assigned to feeding the dairy cows during lactation as well as the dry period brought about a larger burden on the environment. From a perspective of the life cycle, the lowest values of category indicators were represented by the B feed mixture and GG (composed exclusively of cereal grain). B influenced the results of category indicators most favourably for GWP, AP, EP, and PMP, while GG was more influential for POCP, ADP minerals and ADP fossil. Differences in environmental effects in the compared categories between B and other feeds ranged from 28% to nearly 33%. For the GG, environmental impacts categories of POCP, ADP minerals and ADP fossil were lower by 41% to nearly 92% compared to cow feeds mixtures with the highest impact scores. The analysis of results of different category indicators should be conducted against a background of a detailed composition of compound feeds (see Table 1). Only on this basis is it possible to explain more fully the reasons for the variation of impact indicators between the feed types.

The presence of oilseeds (rapeseeds and soybean) in the compound feed composition was clearly associated with higher values of GWP, AP, EP, ADP fossil, ADP minerals and PMP. As mentioned earlier, in the composition of LCC and DRC mixtures there were winter rape and soybean seeds in the proportions of 41.3 and 33.4%, respectively. Research by Holka et al. (2016 and 2017) and Dąbrowicz et al. (2017) showed a higher potential for environmental impact of winter rape cultivation compared with winter wheat and maize for grain. According to these authors, the average values of the indicators per 1 t of rapeseed for GWP, AP and EP and POCP were respectively: 808.5 kg CO_2 eq, 13.1 kg SO_2 eq, 3.35 kg PO_4 eq and 0.18 kg C_2H_4 eq, and for winter wheat: 344.0 kg CO_2 eq, 5.1 kg SO_2 eq, 1.4 kg PO_4 eq and 0.1 kg of C_2H_4 eq. Whereas maize production had low environmental impacts for the ADP minerals and ADP fossil categories with respect to the functional unit of 1 t of grain.

These results indirectly indicate that increasing the share of cereals in feed mixtures while concurrently reducing the share of oilseeds can be an important factor affecting the final values of the category impact indicators of produced feeds. The high values of the POCP indicator of DC and CJ feed mixtures (1.09 and 0.50 kg of C_2H_4 eq) may have been substantiated by the presence of rapeseed and soybean meal in their composition. In the process of oil extraction both from rapeseed and soybean, hexane is used, which has a relatively high characterization factor for POPCP category (0.814 kg of C_2H_4 / kg of substance) (Derwent et al., 1998). Therefore, the hexane emission load most probably affects this impact category of produced feeds in which oil cake is used after extracting the oil via a solvent extraction with hexane. Noticeably higher values of ADP minerals were found in the feed mixtures that had a higher concentration of premixes and mineral salts.

The magnitude of potential environmental effects characterized by different categories of impacts were developed mainly in the phase of upstream processes (Figure 2). This phase groups various manufacturing processes of agricultural means of production for the plant cultivation and processing of secondary commodities made from the raw crops. It includes the emissions accompanying the combustion of fuels and the application of fertilizers in field crops, transport of raw materials to the processing industry, combustion of natural LPG in the processing industry and electricity consumption. The shares of the upstream phase for most of the impact categories were the highest in the production of B and GG. In the ACF, being the virtual average feed product of the feed mill, the upstream process contributed to the impact categories from a minimum of 79.1% for ADP fossil to a maximum of 97.9% for ADP minerals (potentials for depleting abiotic resources). The GWP impact indicator was equal to 88.4% of the final value for this impact category.

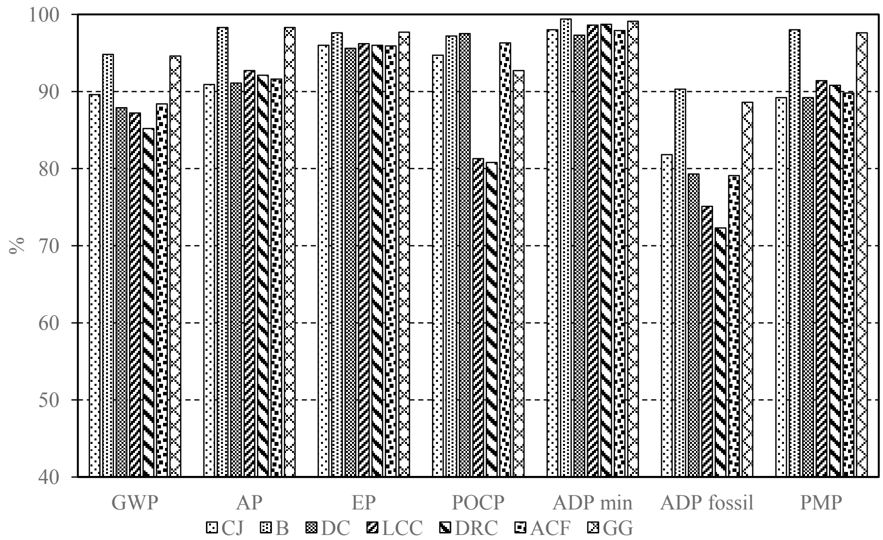

Fig. 2. Relative values of the impact category indicators for the upstream phase of production of different feed types.

Source: authors' own calculations.

The structure of the main processes in the upstream phase affecting the environmental effects of feed production was characterized more broadly for the GWP impact category (Table 5).

The values of the global warming effect in this phase were highest for the LCC and DRC production systems. It is seen that 51-60% of the GWP impact was attributable to the use of oilseeds. The second group of feed components in terms of GHG emissions were cereals, contributing to about 29-30% of GWP. In comparison with oilseeds, the relative importance of cereals in GHG emissions was much lower, even though their share according to the proportion of weight in these feed mixtures was about 49-50%. The third group of products influencing the GHG emissions were co-products of the oil industry, i.e. rapeseed and soybean meal. Their contribution to the GWP impact in the compound feeds in which these co-products were present (CJ, B, DC) was proportional to their relative share according to the compound feed weight. The load on rapeseed meal and soybean meal with GHG emissions is smaller, as the emissions of chemical substances and material streams at the stages of field production and processing are allocated in proportion to the economic value between the main product (vegetable oil) and oil meal. Following this principle, this implies that a greater environmental impact is assigned to primary products of greater economic value compared to by-products. GHG emissions associated with production systems of the compound feeds were least dependent on mineral substances and premixes. This group of components contributed to the total GHG emission in the range of 4.4 to 19%, depending on the type of feed.

Table 5. Main contributing processes to GWP category in the upstream phase of feed supplement production, quantitative comparison of the analyzed feed types, in kg CO_2 eq

Upstream phase	Compound feed type						
	CJ	B	DC	LCC	DRC	ACF	GG
Total:	547.9	495.3	514.7	636.2	585.0	535.6	504.5
Cereals production	357.7	399.8	199.8	185.8	173.6	254.5	504.5
Oilseeds	0	0	0	383.7	300.2	51.2	0
Co-products of oil crushing industry	166.8	28.7	303.4	0	0	199.9	0
Premixes and mineral compounds	23.4	66.8	11.5	66.7	111.2	30.0	0

Source: authors' own calculations.

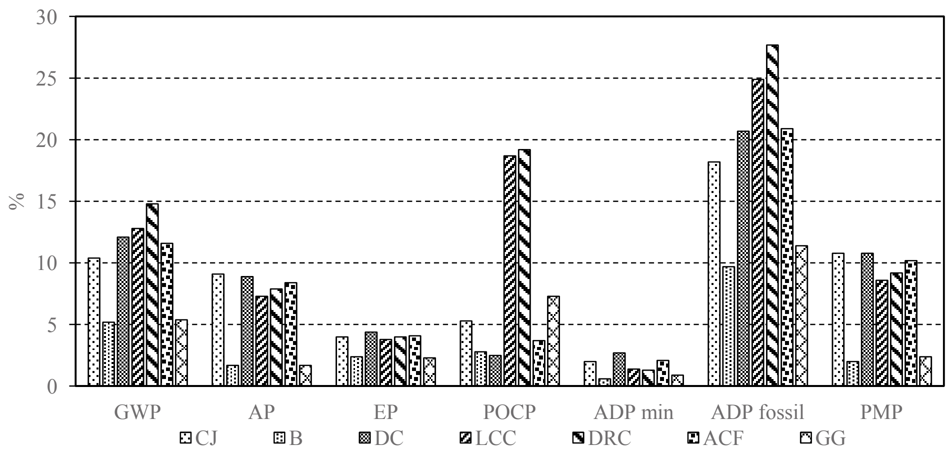

Fig. 3. Relative contribution of core and transport processes in the production of compound feeds to the impact category indicators

Source: authors' own calculations.

Contribution of core and transport processes, characterizing the feed mill itself, to the impact category indicators by the types of feeds produced is presented in Figure 3. In this phase of processes (from gate-to-gate), the DRC feed stood out in the environmental burden related specifically to the GWP, POCP and ADP fossil impact categories. Relatively high values of indicators in the AP, EP, ADP min and PMP impact categories were characterized by the DC compound feed. According to the ACF feed, estimated relative values of indicators ranged on average from 2.1% for ADP minerals to 20.9% for ADP fossil.

Table 6. Main contributing processes to GWP category in the core phase of the compound feed production (quantitative comparison of the analyzed feed types), in kg CO_2 eq

Core phase	Compound feed type						
	CJ	B	DC	LCC	DRC	ACF	GG
Total:	63.6	27.2	70.8	93.4	101.6	70.3	28.8
- manufacturing	22.7	23.6	26.3	49.8	55.6	33.0	26.2
- transport	40.9	3.6	44.5	43.6	46.0	37.0	2.6
of which soybean meal / soybean transport	37.2	0.0	34.9	37.8	38.8	31.9	0.0

Source: authors' own calculations.

Absolute values of the GWP impact of two groups of aggregated processes in the core phase for the analyzed feed types are shown in Table 6. It is seen that the LCC and DRC feeds were differentiated both by a strong impact of the manufacturing processes and the transport of ingredients to the feed mill. Explaining high GWP values is possible by analyzing the composition of compound feeds. Both types of feeds contain maize grain and rapeseeds. According to the technological process description, the whole mass of seeds of both crops is subjected to drying every year due to a high grain moisture content. This is also reflected in the higher consumption of electricity, LPG, diesel combustion and the involvement of machinery in the production of these feeds in the mixing plant (see Table 3). The second factor affecting the value of the GWP indicator is the transport of components for the feed production. In the core phase, the transport used had an average of nearly 53% share in the GWP indicator. The relatively high proportion of transport in the GWP impact is mostly a result of the soybean long transport distances (from South America). Soybean transport accounted for GHG emissions averaging 32 kg CO_2 eq per 1 t of feed mixture, which means that it contributed over 86% of equivalent CO_2 emissions linked to the transportation.

Conclusions

An important element of milk and beef production, which determines an increase in productivity, is compound feeds. The variety of ingredients used (plant products, by-products, mineral compounds from industry, etc.), a complex supply chain and a diverse nature of industrial processes in feed milling plants eventually change the profile of environmental burdens attributed to new products, i.e. compound feeds. The study was aimed at determining the environmental effects of the production system of industrial feeds.

By applying the LCA method and the characterization models, it was possible to consider many impact categories (GWP, AP, EP, POCP, ADP minerals, ADP fossil and PMP). Within the defined system boundaries, the analysis distinguished two stages of the life cycle of feed produced: upstream and core. Inputs incurred in the production of raw materials for the compound feeds, and direct consumption of materials and energy in the feed mill, affect the differences in the level of environmental impacts between different feed types. The analysis of the life cycle of the compound feed production systems in relation to the GWP category allows one to conclude that the pre-production stage of feeds had a predominant impact on GHG emissions. At the core stage (including the transport of ingredients and the production of compound feeds in the feed milling plant), the process of soybean transport exerted the main influence on the increase in the share of transport in the GWP impact category. The presence of crop grains in the feed composition, with initial higher humidity and thus demanding greater consumption of gas and other energy sources for drying, contributed to the increase in the GWP indicator. The results obtained indicate that the most important sources of limiting the environmental impact of feed production are concentrated outside the feed mill gate. The possibilities of improving the environmental effects depend mainly on curbing the emissions related to the field production of plant raw materials. Improving the processes in the feed mill from the point of view of progress in energy efficiency would also lead to a reduction of the environmental impact, but on a smaller scale compared to the upstream processes. Becoming independent of soybean imports from South America by the feed mill would eliminate the environmental burdens associated with transporting over long distances.

The described methodology and the obtained data may constitute the source material for life cycle analyses in the compound feed industry and in the processes of milk and livestock production, as well as in the environmental analyses of the processing industry in the production of animal-based products. At present in Poland, it is not possible to characterize on a national scale the environmental effects of animal products or different production systems using the LCA methodology, because there is no generally available comprehensive database of real unit processes with data on inputs and emission streams. Ensuring the objectivity and representativeness of this type of research would create a need for an information network dedicated to gathering inventory data with a wide range of aspects that contribute to technological changes, regional differences and different productivity levels. The results presented refer to a single feed mill with relatively simple manufacturing processes. Extending the research to other types of feed mills in different geographic locations could give a better insight into the variability of the environmental impact of feed products from the feed mills. This would thus lead to an increase in the accuracy of estimating the impact of the full chain of animal production on the environment.

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