Supplementary material

Comparison of individual food products may underestimate the underlying environmental impacts

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1. System models

1.1. By-product categories

Animal by-products are categorized into three groups according the level of risk to public and animal health, which defines how the products can be utilized (European Union, 2009). Broadly, Cat. 3 material consists of former foodstuffs and by-products that are suitable for human consumption but are not used as food for example for commercial reasons, and blood, hides, skins, hooves, feathers, wool, horns, hair and fur originating from healthy animals. Cat. 2 material is by-products that are declared unfit for human consumption, contain disease risk other than Transmissible spongiform encephalopathies (TSE), animals dead or killed for other than human consumption and manure and digestive tract content. Cat. 1 material contains bodies and body parts suspected of being infected by a TSE, special risk materials, animal other than wild or farmed animals and products containing prohibited substances or environmental toxins above the legal limit. The exact classification criteria is given in European Union (2009).

Table S1. Shares of different product categories from live weight pork (Gac et al., 2014).

Product	*% from live weight*
Meat & edible offal	70 %
Food grade bones	9 %
Cat. 3 material	9 %
Cat. 2 material	5 %
Cat. 1 material	7 %

* Cat. 3 fat included

1.2. Slaughtering

The amount of electricity, natural gas and water consumed in the slaughtering process was obtained from Mogensen et al. (2015). Data concerning masses and uses of beef meat and by-products was obtained directly from meat company (Table S2). The averages from years 2017-2019 were used for calculation of product yields and prices.

Table S2. Inputs and outputs of slaughtering of beef and pork.

BEEF	*Inputs*	*Amount*	*Reference*	*Outputs*	*Amount*	*Reference*
	Bovine animal (live weight)	1kg	Company	Meat and edible offal	0.479 kg	Meat company
	Electricity	0.60 kWh	(Mogensen et al., 2016)	Hides	0.036 kg	Meat company
	Natural gas	0.04 kWh	(Mogensen et al., 2016)	Inedible offal	0.089 kg	Meat company
	Water	0.99 l	(Mogensen et al., 2016)	Cat. 2 material	0.170 kg	Meat company
				Mixture of cat. 3 & 2 material	0.148 kg	Meat company
				Cat. 1 material	0.076 kg	Meat company
PORK	*Inputs*	*Amount*	*Reference*	*Outputs*	*Amount*	*Reference*
	Pork	1 kg		Meat and edible offal	0.7 kg	(Gac et al., 2014)
	Electricity	0.22 kWh	(Reckmann et al., 2013)	Inedible offal*	0.09 kg	(Gac et al., 2014)
	Water	3.33 l	(Reckmann et al., 2013)	Cat. 2 material	0.05 kg	(Gac et al., 2014)
				Mixture of cat. 3 & 2 material	0.09 kg	(Gac et al., 2014)
				Cat. 1 material	0.07 kg	(Gac et al., 2014)

**Includes category 3 fat*

2. By-products

2.1. By-product processing and their alternatives

2.1.1. Processing of hides

Processing hides to leather was modelled based on data adapted from leather LCA study (Joseph and Nithya, 2009) (Table S3), concerning life cycle stages of preservation, tanning and finishing and waste management. Due lack of data wetting agent, preservative, enzymebate, calcium hydroxide and chrome sulphate were not included. The solid waste generated in processing was assumed to be treated as landfill (Notarnicola et al., 2011). As the output amount of finished leather is given as square meters, the output weight of finished leather was assumed to be 20% of raw hides (De Rosa-Giglio et al., 2018).

Table S3. Inputs and outputs of hide processing.

Inputs	*Amount*	*Outputs*	*Amount*
Hides	1 kg	Leather	0.2 kg
Ammonium chloride	0.0167 kg	solid waste	0.5253 kg
Electricity, medium voltage	0.5637 kWh	wastewater	0.0196 kg
Salt	0.4 kg		
Sodium bicarbonate	0.0138 kg		
Sodium carbonate	0.0035 kg		
Sodium formate	0.0124 kg		
Sodium hydrogen sulfate	0.0038 kg		
Sodium sulfide	0.0285 kg		
Sulfuric acid	0.0143 kg		
Water	0.0211 kg		

2.1.2. Pet food and fur animal feed

Inedible offal are processed into pet food, whereas category 2 material is used for fur animal feed. No processing was assumed before point of substitution, since ingredients used for pet food are fresh by-products (FEDIAF, 2018). Since the function of these products is to provide nutrition, especially protein and fat, the substituting amounts were equalized according protein contents derived from FoodData Central (U.S. Department of Agriculture, 2019). The protein content of beef by-products were assumed to be 14.97% (FDC ID: 168630) and pork to 15.03% (FDC ID: 168272) based on protein contents of raw variety meats and by-products (U.S. Department of Agriculture, 2019).

For alternative pet food and fur animal feed, market mix was created by subtracting beef and pork by-products from prepared pet food ingredients (FEDIAF, 2018). The share of ingredients and their protein contents are presented in Table S4 and the data used in modelling is presented in table S5. Chicken by-products used in pet food were assumed to originate 34.6% of live weight of chicken (Ecoinvent market dataset) and allocation to these by-products was done based on economic allocation 3.4% (FEDIAF, 2018). The protein content of pet food alternative was set to 12.13%.

Table S4. Pet food and fur animal feed alternative ingredients and their protein contents. Ingredients adapted from FEDIAF (2018) and protein contents from FoodData Central (U.S. Department of Agriculture, 2019).

Ingredient	*Amount*	*Protein content*	*Protein content reference ID in FoodData Central*
Maize starch	7 %	0 %	FDC ID: 1198449
Maize	15 %	9.42 %	FDC ID: 170288
Rice	3 %	6.61 %	FDC ID: 169760
Wheat grains	21 %	11.31 %	FDC ID: 169719

Wheat flour	13 %	15.10 %	FDC ID: 790085
Soybeans	6 %	36.49 %	FDC ID: 174270
Poultry by-products, fresh	36 %	11.39 %	FDC ID: 171104

Table S5. Inputs and outputs of pet food & fur animal feed alternative.

Inputs	*Amount*	*Outputs*	*Amount*
Poultry by-products	0.36 kg	Pet food/ fur animal feed alternative	1 kg
Maize, grain	0.15 kg		
Maize starch	0.07 kg		
Rice	0.03 kg		
Soybean	0.06 kg		
Wheat flour	0.13 kg		
Wheat, grain	0.21 kg		

2.1.3. MBM and tallow processing

Mixture of by-products are processed by rendering (Ecoinvent: treatment of slaughterhouse waste, rendering, slaughterhouse waste) and the process yields 25% meat and bone meal and 17% tallow (Ecoinvent).

The tallow from the rendering is further processed to biodiesel, which was modelled based on data presented in LCA study of production of biodiesel from rendered lipids (López et al., 2010) (Table S6).

Table S6. Inputs and outputs of biodiesel production from tallow. Adapted from López et al. (2010).

Inputs	*Amount*	*Outputs*	*Amount*
Tallow	1 kg	Biodiesel	0.99 kg
Electricity, medium voltage	0.367 MJ	Glycerol	0.1287 kg
Heat, district or industrial, natural gas	6.974 MJ	sodium chloride, powder	0.0089 kg
Hydrochloric acid, without water, in 30% solution state	0.006 kg	Water	0.004 kg
Methanol	0.099 kg		
Neutralising agent, sodium hydroxide-equivalent	0.004 kg		
Water	0.029 kg		

2.1.4. Anaerobic digestion

Category 1 material is treated with anaerobic digestion. The data concerning biogas yield (208.25 m3CH4/t of feedstock from mixture of paunch, dissolved air flotation sludge and soft offal) was obtained from literature (Ware and Power, 2016). The impacts from anaerobic digestion process were assumed to be similar than treatment of biowaste by anaerobic digestion per treated kilogram of feedstock (Ecoinvent).

2.1.5. Gelatine and pectin

The processing of gelatine was modeled based on conventional production method data adapted from (Ma et al., 2019) (Table S7). Several options for gelatine substitutes exist, but due lack of data gelatine was assumed to be substituted with pectin extracted from pomegranate peels, with pectin being equivalent to gelatine in terms of mass. The pectin production was modelled based on the data presented in the study by (Shinde et al., 2020) using mass allocation between products. No impacts were allocated to pomegranate peels from pomegranate production.

Table S7. Inputs and outputs of gelatine and pectin production. Data concerning gelatine adapted from Ma et al. (2019) and pectin from Shinde et al. (2020).

Gelatine			
Inputs	*Amount*	*Outputs*	*Amount*
Bones	1 kg	Gelatine	0.0699 kg
Electricity	0.1514 kWh	wastewater	23.85 l
Hard coal	0.0079 kg		
Hydrochloric acid	0.4788 kg		
Phosphoric acid	0.0025 kg		
Quicklime	0.1866 kg		
Sodium hydroxide	0.0080 kg		
Water	1611.0 kg		
Land occupation	0.0002 m2*a		
Pectin			
Inputs	*Amount*	*Outputs*	*Amount*
Electricity	4.0681 MJ	Pectin	1 kg
Ethanol	9.1598 kg		

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