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Deliverable 5.3 – Part I

Report on the Life Cycle Assessment Results

Organisation name of lead for this deliverable:

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Dissemination Level		
PU	Public	X
PP	Restricted to other program participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

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0. General remarks

Deliverable 5.3 (D5.3) is dedicated to presenting the results and relevant underlying inventory data and assumptions of the environmental (LCA) and socio-economic (sLCA) impact assessment of P2F food prototypes as compared to existing food alternatives. For reasons of practicability D5.3 consists of two separate reports:

- D5.3 part I: Report on results of the Life Cycle Impact Assessment by ifeu
- D5.3 part II: Report on results of Socio-Economic Assessment by UPM

Due to the iterative character of LCA in general and the innovative nature of P2F prototypes (implying continued changes in product compositions) it was quite challenging to keep both LCA and sLCA modelling updated according to the latest findings in WP 1-3. Several meetings and phone conferences between ifeu and UPM took place in order to ensure alignment of both work streams as much as possible. While minor deviations were unavoidable an overall consistency has eventually been achieved. The food products covered in both assessments are:

- Fiber-like vegetable meat alternative versus chicken breast meat
- Spread-like vegetable meat alternative versus pig meat based Leberwurst (liver paté)
- Vegetable protein milk alternative versus cow milk
- Plant protein rich pasta versus traditional pasta
- Plant protein rich bread versus traditional bread

On request of the EU reviewers and in order to have a larger picture of the potential environmental advantages of meat substitution it was decided to include a comparison of a beef meat burger versus a vegetable burger in the LCA. However, given the timing of this decision and the WP5 design as such it was not possible to include this additional comparison into the socio-economic assessment.

As already mentioned in Deliverable 5.2 (p.52-55 and figure 11) it should be taken into consideration that in this project LCA and sLCA while examining the same products necessarily have different life cycle boundaries. The drivers of the differences between the environmental profiles of the examined food products are found in the upstream supply chain up to the point where the food products are ready for retail. Process steps from there on can be considered to be quite similar and are therefore not further considered in the comparative environmental assessment.

The situation is different for the socio-economic assessment. Here the impact of innovative food solutions on the consumer as compared to traditional food is crucial for the potential success of P2F prototypes on the market. Hence the consumption phase forms part of the socio-economic assessment. In this way it also provides a link to the market analysis carried-out in WP4.

The following chapters provide the documentation of Deliverable 5.3 part I.

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1. Introduction

The following paragraph provides some orientation what is to be found where within the present Deliverable 5.3 part I:

Chapter 2 contains all the documentation related to life cycle inventory data thus representing the key input data for the environmental assessment. The documentation is structured along the value chain, starting from crop cultivation (section 2.1), crop processing (section 2.2), animal husbandry (section 2.3), up to the definition of food products (section 2.4). Mass flow models developed based on those data are to be found in section 2.5. Section 2.6 provides a complete scenario overview bringing together the settings for examined P2F prototypes and their traditional and where applicable also modern reference food products. Here is also a detailed list, which results are to be found where in this report.

Chapter 3 is dedicated to presentation of LCA results, in a sectoral result format (section 3.1) as well as in a condensed net result format for both functional units (section 3.2, protein-based and section 3.3, mass-based). Note: results related to “Plant protein rich pasta versus traditional pasta” as well as “Plant protein rich bread versus traditional bread” can be found in the appendix.

Chapter 4 presents the results of the additional biodiversity and water assessment of P2F prototypes.

Chapter 5 contains a conclusive summary.

One remark regarding wording used throughout this Deliverable 5.3 part I: “vegetable” in this report refers to innovative, vegetable-based P2F prototypes. Modern soy-based reference products are referred to as “soy” throughout this report. “Traditional” refers to animal-based (meat or egg based) reference food products.

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2. Documentation of key input data

2.1. Inventory data for the crop cultivation phase

Selection of geographical reference of crop cultivation models:

Geographic reference of crop cultivation models is determined based on the following procedure:

1. Collection of crop-specific statistical information related to cultivation within EU member countries. This information covers cultivated area per crop and country, harvested amount of seeds per crop and country, as well as obtained yields per crop and country. The information is collected for a five year period or as close as possible to the most up-to-date five year period available
2. A five-year average is calculated per crop and country for all statistical information collected. This average shall level out specific favourable or non-favourable conditions in the cultivation practices (such as weather effects which may lead to exceptionally high or low yields etc.)
3. Based on described statistical information, the top 2 cultivation countries are identified according to cultivated area per crop and country.
4. In a next step, a check is carried out if those top 2 cultivation countries are also the top 2 countries per crop based on harvested amounts of seeds.
5. In a further step, it is checked how the seed yield applied in the LCA models (based on available inventory data for the cultivation phase) corresponds with obtained ranges of yields over the years and different countries.

Figure 2-1 gives an example for European wheat cultivation for step 3 – identification of top 2 cultivation countries. In the wheat example, the top 2 cultivation countries are France and Germany.

Table 2-1 summarizes the result of the identification of the key cultivation countries per crop within the EU. It also documents the typical cultivation regions for overseas crops as assumed for purpose of the LCA models.

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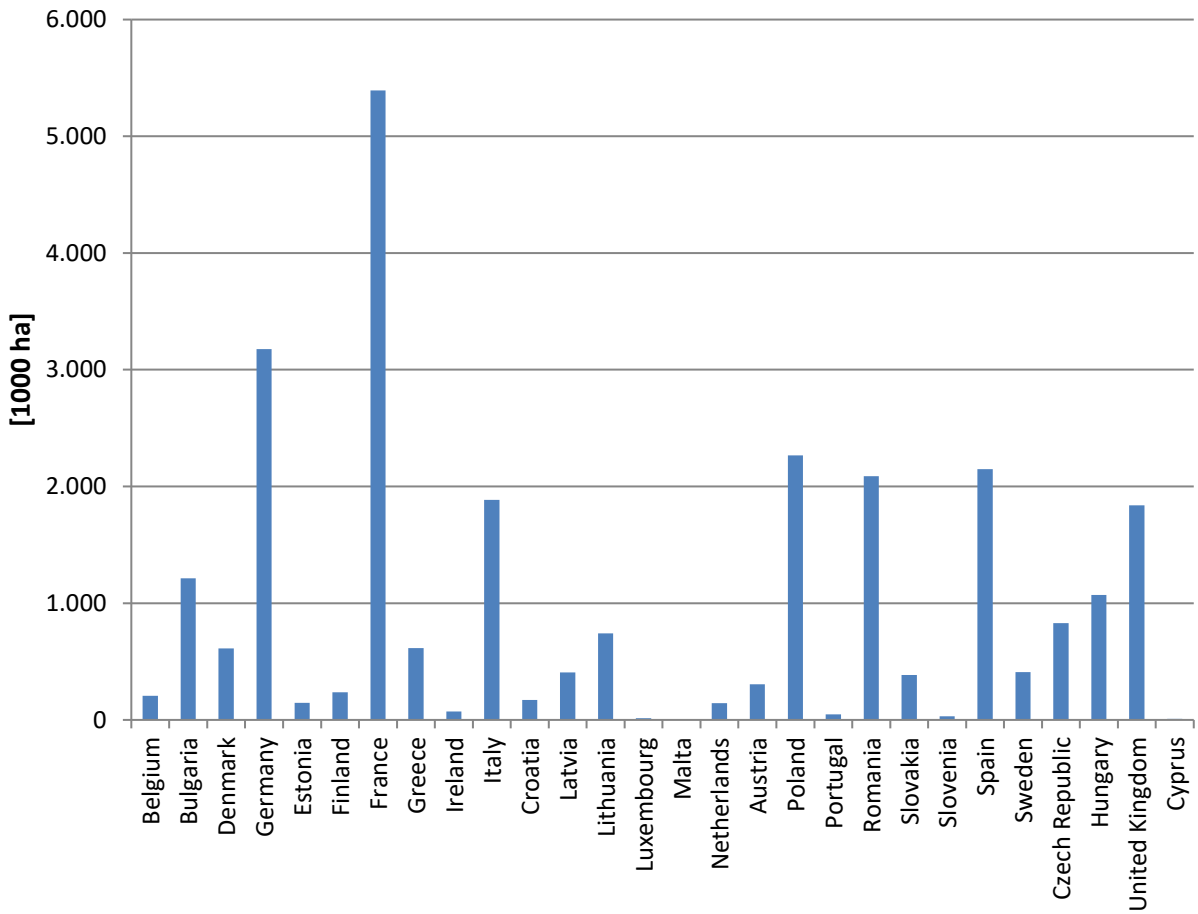

Figure 2-1: Mean area of wheat cultivation in the EU28 by country [average 2012 – 2016, source: FAO]

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Table 2-1: Main cultivation countries and yield ranges within the EU

Crops	Model Yield [t WM*/ha]	Source	Model Region	Main cultivation areas within EU			Yield range top 2 [t WM*/ha]	Source Area & yield range
				1	2	3		
PROTEIN2FOOD								
Quinoa	2,51	Jacobsen et al. 2016 (Denmark)	EU	n.a.	n.a.	n.a.	n.a.	n.a.
Amaranth	2,01	Pulvento et al. 2015 (Italy)	EU	n.a.	n.a.	n.a.	n.a.	n.a.
Buckwheat	1,01	Blonk et al. 2012 (Poland)	EU	Poland	Lithuania	France	1.3-3.7	FAO
(White) Lupin	2,51	KTBL	EU	Poland	Germany	France	1.6-1.7	FAO[1]
Lentil	0,81	KTBL	EU	Spain	France	Bulgaria	0.6-1.4	FAO
Faba Bean	3,51	KTBL	EU	France	UK	Italy	3.2-3.8	FAO
OTHERS (EU crops)								
Wheat	7,9	KTBL	EU	France	Germany	Poland (UK by mass)	6.9-8.0	Eurostat
Maize	9,8	KTBL	EU	France	Romania	Hungary (Germany by mass)	3.8-8.7	Eurostat
Rapeseed	3,4	KTBL	EU	France	Germany	Poland	3.0-3.5	FAO
Sunflower	3,02	KTBL	EU	Romania	Bulgaria	Spain (Hungary by mass)	2.0-2.3	Eurostat
Spring Pea	3,52	KTBL	EU	France	UK	Hungary	4.5-7.4	FAO
Sugar Beet	60,02	KTBL	EU	France	Germany	Poland	73-87.3	FAO
Rye	5,01	KTBL	EU	Germany	Poland	Denmark	2.9-5.8	FAO
Tomato	70,81	Manfredi + Vignali, 2013 (Italy)	EU	Italy	Spain	Greece	55.9-84.9	FAO
Lemon/Citron	36,91	IFEU database (Spain)	EU	Spain	Italy	Portugal	14.3-22.8	Eurostat/FAO
Soybean (food)	2,11	SoyEurope, 2017	EU	Italy	Serbia	France	2.6-3.4	SoyEurope
OTHERS (oversea crops)								
Soybean (feed)	2,82	BioEM, 2016 (BR/AR)	Brazil	n.a.	n.a.	n.a.	n.a.	n.a.
Oil Palm	192	BioEM, 2016	Malaysia	n.a.	n.a.	n.a.	n.a.	n.a.
Coconut	4,41	FAO	Philippines	n.a.	n.a.	n.a.	n.a.	n.a.
Pineapple	86,01	Stössel et al. 2012	Costa Rica	n.a.	n.a.	n.a.	n.a.	n.a.

1 The data refer to a mixture of different types of lupins

* WM: wet mass, this means that all yield data refer to wet mass of the crops

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Development of crop cultivation models for LCA purposes:

The principles for development of crop cultivation models for LCA purposes were described in section 2.5.1 of Deliverable 5.2. The following tables 2-2 to 2-4 summarize the results of the data collection carried out for the key cultivation parameters per crop and their respective data sources. Main data sources are primary data obtained from P2F project partners (WP1) as well as secondary data sources, such as crop-specific literature.

Table 2-2: Key Cultivation parameters of lentil, faba bean and blue lupin

Topic	Unit	LENTIL	Comment / data source	FABA BEAN	Comment / data source2	BLUE LUPIN	Comment / data source3
PROTEIN2FOOD							
Amount of irrigation water used	m³ / ha	0		0		0	
Diesel from sowing up to harvest (including harvesting)	L / ha	11.52	1	53.00	1	84.00	2
Nitrogen fertilizer (total mineral fertilizer as N - or otherwise please specify)	kg N/ ha	0	0	0	0	0	0
Share of Urea-N in above fertilizer-N	%	21	3	21	3	21	3
Potassium fertilizer (as K2O - or otherwise please specify)	kg K2O / ha	19.2	4	140	4	90	4
Magnesium fertilizer (as MgO - or otherwise please specify)	kg MgO / ha	4.8	4	17.5	4	12.5	4
Phosphorus fertilizer (as P2O5 - or otherwise please specify)	kg P2O5 / ha	9.6	4	52.5	4	32.5	4
Seeds	kg/ha	25	9	105	4	171	4
Pesticides	kg active ingredient	1.3	10	1.9095	11	0	
Crop yield (refers to water content of crop after drying)	kg / ha	800	4	3500	4	2500	4
Water content of crop at harvest	%	20	5	17	6	16	6
Is the crop dried after harvest (for storage)?		yes		yes		yes	
If yes: water content of crop after drying	%	14	5	14	6	14	6
Nitrogen fixation from air during plant growth	kg N / ha	91	4	175	4	150	4
Residual nitrogen in soil after harvest	kg N / ha	21	4	31	8	30	4

1 ifeu assumption
2 ifeu assumption, similar to wheat
3 IFA (Western and Central Europe, Average 2010 to 2014)
4 KTBL (2018) (Germany)
5 Landwirtschaftliches Technologiezentrum Augustenberg (2018) (Germany)
6 ifeu assumption based on KTBL (Germany)
7 KTBL/Sulas et al. (2016) (Germany/Southern Italy)
8 Sulas (2013) (Southern Italy)
9 Blonk (Turkey)
10 Blonk (used for Turkey, general data for pulses)
11 LBI (Netherlands)

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Table 2-3: Key Cultivation parameters of white lupin, quinoa and amaranth

Topic	Unit	WHITE LUPIN	Comment / data source	QUINOA	Comment / data source	AMARANTH	Comment / data source
PROTEIN2FOOD							
Amount of irrigation water used	m³ / ha	0		2300		1378	
Diesel from sowing up to harvest (including harvesting)	L / ha	84	2	75	12	75	13
Nitrogen fertilizer (total mineral fertilizer as N - or otherwise please specify)	kg N/ ha	0		120	14	120	15
Share of Urea-N in above fertilizer-N	%	21	3	21	3	21	3
Potassium fertilizer (as K2O - or otherwise please specify)	kg K2O / ha	90	4	0		20	17
Magnesium fertilizer (as MgO - or otherwise please specify)	kg MgO / ha	12.5	4	0		0	
Phosphorus fertilizer (as P2O5 - or otherwise please specify)	kg P2O5 / ha	32.5	4	40	18	70	17
Seeds	kg/ha	315	4	0		10	15
Pesticides	kg active ingredient	1.2575	11	0.4	19	0	20
Crop yield (refers to water content of crop after drying)	kg / ha	2500	4	2000	14	1975	21
Water content of crop at harvest	%	16	6	18	19	12	15
Is the crop dried after harvest (for storage)?		yes		yes		no	
If yes: water content of crop after drying	%	14	4	12	12	12	15
Nitrogen fixation from air during plant growth	kg N / ha	160-180	7	0		0	
Residual nitrogen in soil after harvest	kg N / ha	33	4	0		0	

2 ifeu assumption, similar to wheat
3 IFA (Western and Central Europe, Average 2010 to 2014)
4 KTBL (2018) (Germany)
6 ifeu assumption based on KTBL (Germany)
7 KTBL/Sulas et al. (2016) (Germany/Southern Italy)
11 LBI (Netherlands)
12 UCPH PLEN (Denmark)
13 ifeu assumption as QUINOA
14 Jacobsen et al. (2016) (Denmark)
15 CNR (Italy)
17 Mujica (1994) (Peru)
19 SATEAN (Romania)
20 ifeu assumption based on CNR information
21 Pulvento et al. (2015) (Italy)

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Table 2-4: Key Cultivation parameters of buckwheat and European soybean

Topic	Unit	BUCKWHEAT	Comment / data source	SOYBEAN	Comment / data source
PROTEIN2FOOD					
Amount of irrigation water used	m³ / ha	0		1000	
Diesel from sowing up to harvest (including harvesting)	L / ha	84	2	60	1
Nitrogen fertilizer (total mineral fertilizer as N - or otherwise please specify)	kg N/ ha	20	16	0	
Share of Urea-N in above fertilizer-N	%	21	3	21	3
Potassium fertilizer (as K2O - or otherwise please specify)	kg K2O / ha	20	16	125	4
Magnesium fertilizer (as MgO - or otherwise please specify)	kg MgO / ha	0		37	4
Phosphorus fertilizer (as P2O5 - or otherwise please specify)	kg P2O5 / ha	20	16	62	4
Seeds	kg/ha	90	11	133	4
Pesticides	kg active ingredient	0	16	1.9	1
Crop yield (refers to water content of crop after drying)	kg / ha	1026	16	2200	4
Water content of crop at harvest	%	20	22	20	23
Is the crop dried after harvest (for storage)?		yes		yes	
If yes: water content of crop after drying	%	14	22	13	23
Nitrogen fixation from air during plant growth	kg N / ha	0		0	4
Residual nitrogen in soil after harvest	kg N / ha	0		0	24

1 ifeu assumption
2 ifeu assumption, similar to wheat
3 IFA (Western and Central Europe, Average 2010 to 2014)
4 KTBL (2018) (Germany)
11 LBI (Netherlands)
16 Blonk et al. (2012) (used for Poland, derived based on US data)
22 ifeu default
23 ifeu based on Landwirtschaftliches Technologiezentrum Augustenberg (2018)
24 ifeu assumption as KTBL N balance is negative

2.2. Crop processing

An overview of the sub-processes implemented in the crop processing models for innovative, modern and traditional food products is given in Deliverable 5.2.

2.2.1. Crop processing for innovative products

Data on energy requirements, yields and processing materials were collected from P2F project partners (WP2) for following P2F crop processing stages:

- protein isolate processing

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  - lupin protein isolate processing (drying - de-hulling – flaking/milling – de-oiling – pre-extraction – protein extraction – protein precipitation - neutralisation & drying)
  - lentil protein isolate processing (drying - de-hulling – milling – extraction & centrifugation – precipitation & centrifugation - neutralisation & drying)
- flour processing:
  - buckwheat flour (drying - de-hulling – milling - classification)
  - faba bean flour processing (drying - de-hulling – starch removal – protein extraction – drying)
  - quinoa flour processing (drying - de-hulling – milling - classification)
  - amaranth flour processing (drying - de-hulling – milling - classification)

Processing data gaps where primary data is missing have been filled with secondary data sources. Besides data from databases like Ecoinvent 3 and Agrifootprint 2, public industry-wide datasets (e.g. unit process data on oil mills commissioned by FEDIOL, the European association of vegetable oil and meal producers) or ifeu-internal/in-house datasets were used to supplement data gaps.

Primary data collected from P2F partners typically refers to pilot (or lab) scale. Therefore, datasets reflecting small/medium industrial scale are generated. The following key system parameters were adjusted in order to reflect the small/medium industrial scale [1]:

- Decrease of protein loss to hull fractions for de-hulled crops (e.g. lupin)
- Decrease of protein loss to by-product fractions (e.g. % protein in starch by-product fractions, e.g. quinoa)
- Increase of protein drying yields (ex. lupin)
- Increase of energy efficiency (ex. de-oiling)

For the crop processing, economic allocation criteria are applied. In case of the innovative crop processing steps, the approach cannot be implemented as easily as for the established processes, As information on potential value and use of further products and by-products due to the novel character of those products is very limited, the factors have been estimated within a working group composed of IVV, UCPH-Food, UCC as well as IFEU.

Processing data for coconut oil, canola oil and pineapple puree are based on the mentioned secondary data sources.

2.2.2. Crop processing for modern and traditional products

Crop processing data for modern and traditional plant-based food products and feed crops are based on secondary data. Oil milling data have been derived from unit process data on oil mills commissioned by FEDIOL (the European association of vegetable oil and meal producers). Feed mixing plants are based on ifeu-internal/in-house datasets.

For the crop processing, economic allocation criteria are applied. Market price averages are preferably based on several years (e.g. 5 years), in order to even out very short-term price change effects. The prices are taken from following data sources:

- soybean oil and –meal: CBOT[2]

[1] Note: the list named here is of preliminary nature and may be revised / extended in further course of the P2F project

[2] Chicago Board of Trade [http://www.indexmundi.com/commodities/?commodity=soybean-meal&currency=brl **and** http://www.indexmundi.com/commodities/?commodity=soybean-oil&currency=brl] last accessed 04/08/2017

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- rapeseed oil and –meal: MATIF[3]
- crude palmoil and -kernel: MPOC[4]

2.3. Animal husbandry

Environmental performance of animal husbandry systems depends on numerous system parameters. Among the most decisive ones are parameters related to feed requirements, such as:

- The feed conversion ratio (this defines how much feed is required per kg animal live weight)
- The feed mix composition (what are the main components and what is their mixing ratio)

In order to provide insight into the magnitude of bandwidths that can be expected for the environmental performance of traditional meat systems, two LCA models per meat type have been built for purpose of the P2F project. For those models, the feed conversion ratio is set to a minimum and maximum value as far as it could be derived from publicly accessible data (e.g. different LCA databases such as Agrifootprint V2.0 and Ecoinvent V3).

Consequently, two scenarios have been developed for broilers, pigs and milk cows, respectively. They will be referred to as "low impact" and "high impact" scenarios throughout this report. "Low" in this case is intended to reflect the setting where one expects *lower* environmental impacts, e.g. due to lower amount of feed required per functional unit. The following table 2-5 summarizes the feed requirement characteristics that are changed for "low" versus "high" scenarios.

Table 2-5: Parameter settings for "low impact" and "high impact" scenarios for chicken, pig and milk cow husbandry

Parameter	"LOW impact" scenario	"HIGH impact" scenario
Feed conversion ratio	low feed conversion ratio (corresponds to minimum feed required per kg live weight)	high feed conversion ratio (corresponds to maximum feed required per kg live weight)

The following sections 2.3.1 to 2.3.4 summarize key assumptions along with respective data sources for each of the animal husbandry systems.

2.3.1. Broiler

The most important characteristics of broiler husbandry as implemented in the LCA model are described in the following:

- Model includes the raising of broiler parents, the egg hatching in a hatchery as well as the broiler husbandry from 1-day chicks up to slaughtering age
- Model represents an intensive broiler production in closed stables (which means fast-growing breeds are used and broiler production period is relatively short)
- Broiler husbandry period is ~ 40 days
- Feed composition is summarized in the following table 2-6

[3] Marché à Terme International de France [http://www.indexmundi.com/commodities/?commodity=rapeseed-oil&currency=brl **and** http://www.proplanta.de/Markt-und-Preis/MATIF-Rapsschrot/] last accessed 04/08/2017] last accessed 04/08/2017
[4] Malaysian Palm Oil Council [http://www.mpoc.org.my/Market_Statistics_And_Prices.aspx] last accessed 04/08/2017

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- Further life cycle inventory data are taken from Agrifootprint 2.0 and Ecoinvent V3

Table 2-6: Feed mix broiler, taken from (Agrifootprint 2.0)*

Feed component	% Share in feed mix	Crop Origin	Processing region
Soy meal	33 %	Brazil	26 % Brazil 74 % Europe
Rapeseed meal	13 %	Europe	Europe
Palm oil	7 %	Malaysia	Malaysia
Wheat	21 %	Europe	Europe
Corn	26 %	Europe	Europe

*Note: feed mix modified regarding unspecified feed inputs specified in the original source

2.3.2. Pork

The most important characteristics of pig husbandry as implemented in the LCA model are described in the following:

- Model includes the sow/piglet husbandry as well as the pig fattening up to slaughtering age
- Pig fattening starts from piglet weight ~ 25 kg and ends with a pig live weight ~ 120 kg at slaughtering age
- Pig husbandry period is ~ 17 weeks
- Model represents an intensive pig fattening system in closed stables
- Stables are assumed to be partly equipped with emission reduction systems that reduce ammonia and particulate matter (PM2.5) emissions to air
- Feed composition is summarized in the following table 2-7
- Further life cycle inventory data are taken from Agrifootprint 2.0

Table 2-7: Feed mix pig , taken from (Agrifootprint 2.0)*

Feed component	% Share in feed mix	Crop Origin	Processing region
Soy meal	13 %	Brazil	26 % Brazil 74 % Europe
Rapeseed meal	11 %	Europe	Europe
Palm oil	1 %	Malaysia	Malaysia
Palm kernel	3 %	Malaysia	Malaysia
Wheat	67 %	Europe	Europe
Corn	3 %	Europe	Europe
Sugarbeet pulp	2 %	Europe	Europe

*Note: feed mix modified regarding unspecified feed inputs specified in the original source

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2.3.3. Milk cow

The most important characteristics of milk cow husbandry as implemented in the LCA model are described in the following:

- Model includes typical milk cow herd animal distribution (milk cows, young female calves and a few male calves up to 2 years, heifers, bulls)
- Milk yield is assumed to be ~ 8000 L milk per milk cow and year
- Model represents an intensive milk cow husbandry system in closed stables with less than 10 % pasture time per milk cow and year
- Overall feed composition is summarized in the following table 2-8
- Composition of concentrate feed mix is summarized in table 2-9
- Further life cycle inventory data are taken from Agrifootprint 2.0 and Ecoinvent V3

Table 2-8: Feed mix milk cow, taken from (Agrifootprint 2.0)

Feed component	% Share in feed mix (refers to wet mass)	Crop origin	Processing region
Concentrate feed mix	12 %	see following table 2-9	see following table 2-9
Maize silage	23 %	Europe	Europe
Grass silage	66 %	Europe	Europe

Table 2-9: Concentrate feed mix milk cow, taken from (Agrifootprint 2.0)*

Feed component	% Share in concentrate feed mix	Crop origin	Processing region
Soy meal	15 %	Brazil	26 % Brazil, 74 % Europe
Rapeseed meal	15 %	Europe	Europe
Palm oil	10 %	Malaysia	Malaysia
Wheat	19 %	Europe	Europe
Corn	17 %	Europe	Europe
Sugarbeet pulp	24 %	Europe	Europe

*Note: feed mix modified regarding unspecified feed inputs specified in the original source

2.3.4. Beef

The most important characteristics of beef husbandry as implemented in the LCA model are described in the following:

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- Model includes raising of mother cows for breeding and herd replacement and beef husbandry up to slaughtering age
- Beef husbandry period is assumed ~ 2 years
- Typical slaughtering live weight is ~ 650 kg
- Model represents an intensive beef husbandry system in closed stables
- Overall feed composition is summarized in the following table 2-10
- Composition of concentrate feed mix is summarized in table 2-11
- Further life cycle inventory data are taken from (Agrifootprint 2.0)

Table 2-10: Feed mix beef, taken from (Agrifootprint 2.0)*

Feed component	% Share in feed mix (refers to wet mass)	Crop origin	Processing region
Concentrate feed	6 %	see following table 2-11	see following table 2-11
Grass silage	94 %	Europe	Europe

*Note: grass silage share in feed mix modified relative to the original source in order to adapt for a closed stable system

Table 2-11: Concentrate feed mix beef*

Feed component	% Share in concentrate feed mix	Origin crop	Processing region
Soy meal	12 %	Brazil	26 % Brazil 74 % Europe
Rapeseed meal	15 %	Europe	Europe
Wheat	47 %	Europe	Europe
Corn	21 %	Europe	Europe
Sugarcane molasse	5 %	Brazil	Brazil

*Note: feed mix modified regarding unspecified feed inputs specified in the original source

2.4. Definition of food products

Preliminary composition tables of food products developed within the P2F project were presented in Chapter 2.2.1 of Deliverable 5.1. The composition tables serve as the key starting point for setting up the modular LCA/mass flow models. In this section, the final composition of food products selected for environmental assessment is presented along with the composition of the corresponding reference food products present on the market.

The selection of individual food products within a food product group is based on the outcomes of WP3 of the P2F project. Those are for example the food prototypes with favourite recipes, e.g. based on taste and food property criteria. Composition tables underlying the environmental assessment presented in this report are documented in the following sections 2.4.1 to 2.4.4.

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Besides the composition data, the tables contain the average nutritional information, such as total energy, total fat, carbohydrate and protein content. Those data are e.g. required in order to define the product mass flows as required for the functional unit (e.g. in order to show a food product comparison based on equal amount of protein delivered to the body). For documentation of reference flows depending on functional units see also section 2.6.

2.4.1. Fiber-like vegetable meat alternative (VMA-fiber)

Within WP3, several variants of vegetable meat alternatives with fiber-like structural properties (VMA-fiber) are under development. First results indicate that prototypes based on lentil or lupin isolates combined with amaranth or buckwheat flour will most likely rank among the favourites based on sensory evaluation and taste criteria. Hence, those combinations were selected to undergo the environmental assessment. The following table 2-12 shows the composition of VMA-fiber prototypes under examination as well as their assumed nutritional values.

Table 2-12: Assumed composition and corresponding nutrition values for P2F prototype VMA-fiber (source: WP3)

Composition	**per 100 g***
Water [g]	~ 60
Lentil or lupin protein isolate [g]	~ 30
Amaranth or buckwheat flour [g]	~ 10
Average nutrition values	
Total energy [kcal]	136
Total fat content [g]	1
Total carbohydrate content [g]	5
Total protein content [g]	30

*Note: composition values are rounded and thus may not add up to 100 g

Accordingly, the following table 2-13 shows the corresponding values for traditional chicken meat as the reference food product.

Table 2-13: Composition and corresponding nutrition values for reference product: traditional chicken meat*

Composition	**per 100 g***
Chicken meat [g]	100
Average nutrition values**	
Total energy [kcal]	119
Total fat content [g]	3.1
Total carbohydrate content [g]	0
Total protein content [g]	21.4

*Note: composition values are rounded and thus may not add up to 100 g
**Nutrition value of a typical chicken breast, raw

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2.4.2. Spread like vegetable meat alternative (VMA-spread)

Within WP3, several variants of vegetable meat alternatives with spread like structural properties (VMA-spread) are under development. Three of the VMA-spread prototypes are selected for environmental assessment. Those are the three final recipes that have been picked out by WP3 based on sensory evaluations.

The three selected VMA-spread prototypes are:

- Buckwheat-lupin spread type **LEBERWURST (liver pâté)**
- Buckwheat-lupin spread type **TOMATO**
- Quinoa-faba bean spread type **CURRY**

The following table 2-14 shows the composition range of the three VMA-spread prototypes under examination. For a more detailed description see Deliverable 3.2.

Table 2-14: Composition ranges for P2F prototypes VMA-spread (source: WP3)

Composition	per 100 g*
Water [g]	39-52
Legume/Pseudocereal flour [g]	13-21
Oil [g]	10- 15
Lupin protein isolate [g]	0-6
Other ingredients [g]	9-33

*Note: composition values are rounded and thus may not add up to 100 g

The following tables 2-15 to 2-17 document the nutrition values for the selected VMA- spread prototypes:

Table 2-15: Nutrition values for P2F prototype VMA-spread type LEBERWURST (liver pâté) (source: WP3)

Average nutrition values	per 100 g
Total energy [kcal]	247.3
Total fat content [g]	15.9
Total carbohydrate content [g]	11.7
Total protein content [g]	12.5

Table 2-16: Nutrition values for P2F prototype VMA-spread type TOMATO (source: WP3)

Average nutrition values	per 100 g
Total energy [kcal]	287.2
Total fat content [g]	16.8
Total carbohydrate content [g]	17.9
Total protein content [g]	14.1

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Table 2-17: Nutrition values for P2F prototype VMA-spread type CURRY (source: WP3)

Average nutrition values	per 100 g
Total energy [kcal]	261.5
Total fat content [g]	18.8
Total carbohydrate content [g]	8.4
Total protein content [g]	12.8

Accordingly, the following tables 2-18 shows the corresponding composition ranges and nutrition values for traditional meat-based spread types that serve as the traditional reference food product.

Table 2-18: Composition and corresponding nutrition values for main reference product: traditional spread type LEBERWURST variants*

Composition	per 100 g*
Pork meat + Bacon [g]	49-63
Pig liver [g]	34-38
Other ingredients [g]	3- 13
Average nutrition values*	
Total energy [kcal]	320
Total fat content [g]	30
Total carbohydrate content [g]	0
Total protein content [g]	15

*Note: composition values are rounded and thus may not add up to 100 g
**nutrition values based on an average liver pâté

2.4.3. Vegetable milk

Within WP3, vegetable milks are under development. One promising vegetable milk is selected for environmental assessment. Its macronutrients are in principle comparable with cow milk's macronutrients. Innovative vegetable milk is compared with both traditional cow milk as well as modern soy milk as reference systems. In case of soy milk, the origin of soybeans is assumed to be Europe due to the presence of European-soy based milk products on the market. It should be kept in mind that it is assumed for the P2F project that European soybeans are not associated with any direct land use change effects.

The following tables 2-19 to 2-20 show composition and nutrition values assumed for traditional and modern reference milk products, respectively.

Table 2-19: Composition and corresponding nutrition values for reference product: **traditional cow milk***

Composition	per 100 g**
Cow milk [g]	100
Average nutrition values*	
Total energy [kcal]	67
Total fat content [g]	3.8
Total carbohydrate content [g]	4.8
Total protein content [g]	3.3

* whole milk, 3.8 %
**Note: composition values are rounded and thus may not add up to 100 g

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Table 2-20: Composition and corresponding nutrition values for reference product: **modern soy milk**

Composition	per 100 g
Water [g]	84.1
Soybean [g]	13.1
Sugar [g]	2.8
Average nutrition values	
Total energy [kcal]	54
Total fat content [g]	1.8
Total carbohydrate content [g]	6
Total protein content [g]	3.3

*Note: composition values are rounded and thus may not add up to 100 g

2.4.4. Vegetable burgers

Vegetable burgers are currently under development as traditional meat burger substitutes and a few are already present on the market, typically produced by SME[5]s. Within WP3, both a lentil-based and a lupin-based vegetable burger have been developed. Those are selected for the environmental assessment.

Innovative vegetable burgers are compared with a soy burger based on tofu/okara and further vegetables as a modern reference system. For this vegetable burger, the origin of soybeans is assumed to be Europe, thus no soy import takes place for the vegetable burger. It should be kept in mind that it is assumed for the P2F project that European soybeans are not associated with any direct land use change effects.

Related composition and nutrition data are presented in the following table 2-21 and table 2-22 for the vegetable and soy burger, respectively.

Accordingly, the following table 2-18 shows the corresponding composition ranges and nutrition values for traditional beef burgers that serve as the traditional reference food product.

Table 2-21: Composition and corresponding nutrition values for **lupin/lentil burger**

Composition lentil/lupin	per 100 g*
Water	28.4
Other vegetables [g]	25
Pseudocereals	8.7
Oat flakes	27.5
Lentil/lupin protein isolate	7.1/7.6
Oil [g]	0.8
Salt [g]	0.9
Average nutrition values	
Total energy [kcal]	149/169
Total fat content [g]	2.5/3.5
Total carbohydrate content [g]	19.4/21.2
Total protein content [g]	11.3/12.1

*Note: composition values are rounded and thus may not add up to 100 g

[5] Small and medium enterprises

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Table 2-22: Composition and corresponding nutrition values for **soy burger**

Composition	per 100 g*
Tofu + Okara [g]	83.1
Other vegetables [g]	16
Oil [g]	6
Salt [g]	0.9
Average nutrition values	
Total energy [kcal]	159.8
Total fat content [g]	11.2
Total carbohydrate content [g]	2.1
Total protein content [g]	13.6

*Note: composition values are rounded and thus may not add up to 100 g

Table 2-23: Composition and nutrition values for reference product **beef burger** (*source: ifeu assumption)

Composition*	per 100 g**
Beef [g]	76
Onion [g]	7
Wheat [g]	7
Water [g]	4
Average nutrition values**	
Total energy [kcal]	260
Total fat content [g]	22
Total carbohydrate content [g]	2
Total protein content [g]	14

**Source: http://www.minahalal.com/products/frozen-products/beef burgers/
*Note: composition values are rounded and thus may not add up to 100 g

2.5. Development of mass flow models (flow charts)

Deliverable 5.1 presented preliminary flow charts based on the preliminary prototype composition (figures 3 to 10 in Deliverable 5.1). In this section, corresponding flow charts are shown in Figure 2-2 to Figure 2-13, based on the composition tables documented in the previous section 2.4 that serve as the key input for the prototype LCAs. Furthermore, flow charts are complemented with relevant mass flows at the ingredient and crop level, depending on degree of confidentiality.

The flow charts depict:

- The gray dashed line, framing the whole flowchart, constitutes the system boundary
- The process chains from raw material sourcing to the final food product
- Mass flows for crops required as food ingredients raw materials
- Transportation processes are represented by a framed “T”

Note regarding the crop mass flows shown in the flow charts: The crop mass flows shown are the total mass flows, thus including the crop mass required for sidestreams (e.g. starch fractions) obtained along the processing chain from crop up to the food product.

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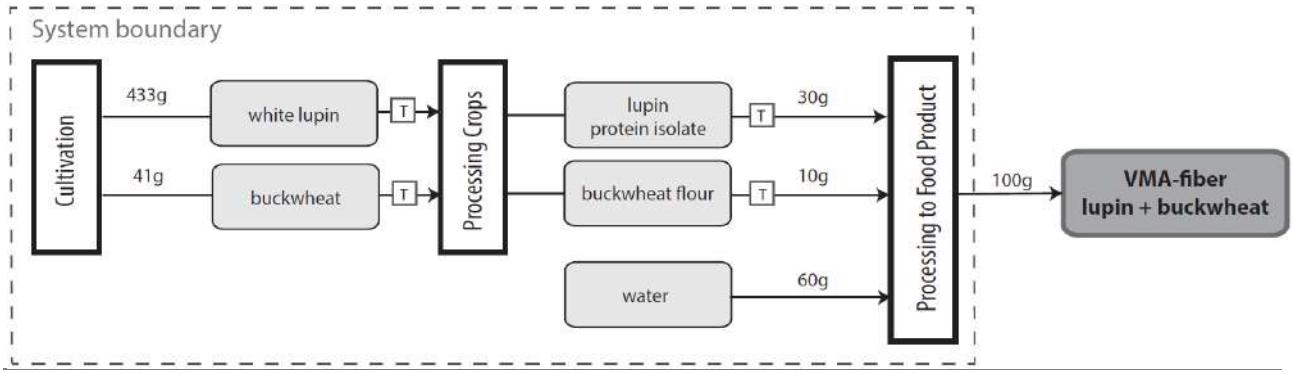
Not shown in the flow charts are processes of energy supply, storage and production of auxiliary materials, manure (in case of animal based systems). This is just for simplification purposes to enhance readability of the flow charts, but all those processes are implemented the final LCA models.

Obviously there are more or less complex process systems behind the three main process steps shown (e.g. "processing" of sunflower grain into native sunflower oil comprises cold-pressing, filtration). Here too, those underlying sub-processes are implemented in the final LCA models.

For traditional reference products, more than one mass flow number per arrow may be found in the flow chart. In this case, the first one refers to the „low impact" and the second one to the „high impact" scenario. For background information on "low impact and "high impact" scenarios please see sections 2.3 and 2.6.

2.5.1. Flow charts VMA-fiber

Figure 2-2 to Figure 2-5 illustrate processes along the value chain as well as mass flows at the ingredient and crop level for the four examined VMA-fiber prototypes. The corresponding flow chart for the traditional reference system chicken meat can be found in Figure 2-6.



1. This illustration excludes energy supply, side streams along the process chain, food/ingredient losses, auxiliary materials and process and cooling water flows
2. This illustration shows primarily the harvesting mass flows of the crops (wet mass); minor mass flows may be excluded from the illustration
3. The harvesting mass flows shown are total mass flows thus include crop mass required for side streams along the process chain
4. This illustration and the LCA model exclude mass flows omitted based on cut-off criteria (section 2.2. in Deliverable 5.2)

Figure 2-2: Process flow chart of P2F VMA-fiber lupin and buckwheat

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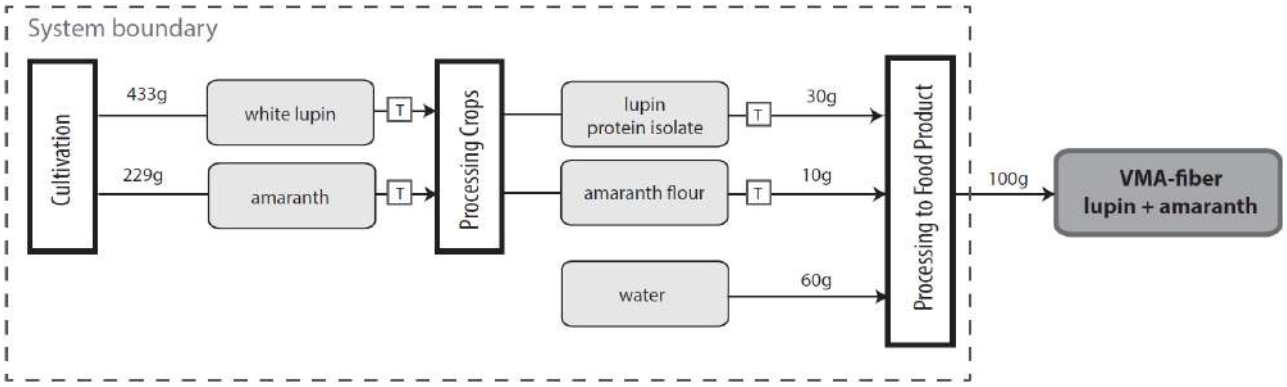

1. This illustration excludes energy supply, side streams along the process chain, food/ingredient losses, auxiliary materials and process and cooling water flows
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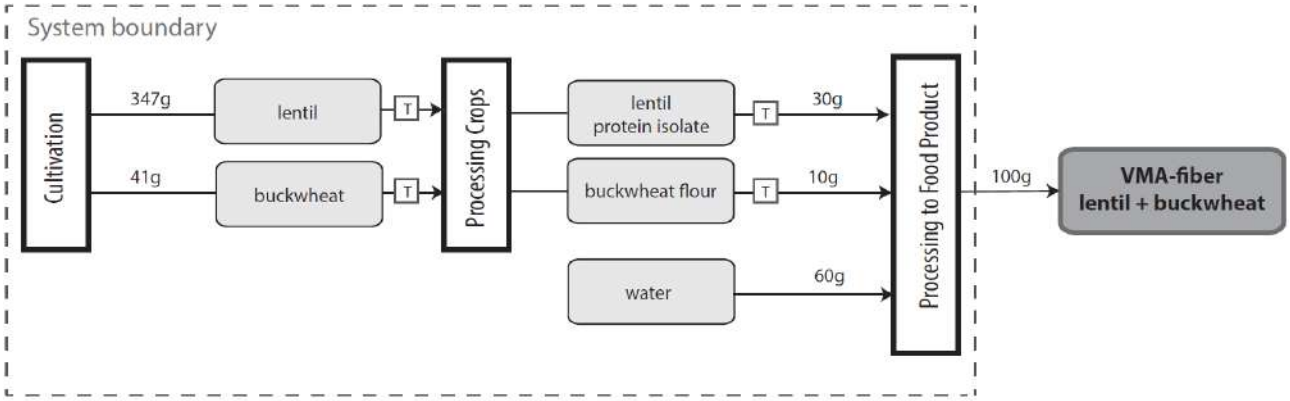
4. This illustration and the LCA model exclude mass flows omitted based on cut-off criteria (section 2.2. in Deliverable 5.2)

Figure 2-3: Process flow chart of P2F VMA-fiber lupin and amaranth



1. This illustration excludes energy supply, side streams along the process chain, food/ingredient losses, auxiliary materials and process and cooling water flows
2. This illustration shows primarily the harvesting mass flows of the crops (wet mass); minor mass flows may be excluded from the illustration
3. The harvesting mass flows shown are total mass flows thus include crop mass required for side streams along the process chain
4. This illustration and the LCA model exclude mass flows omitted based on cut-off criteria (section 2.2. in Deliverable 5.2)

Figure 2-4: Process flow chart of P2F VMA-fiber lentil and buckwheat

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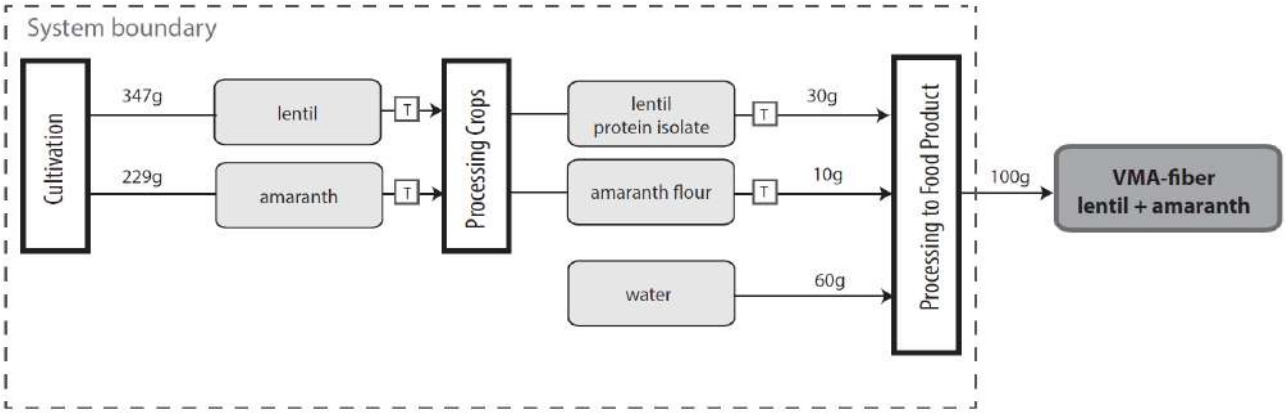
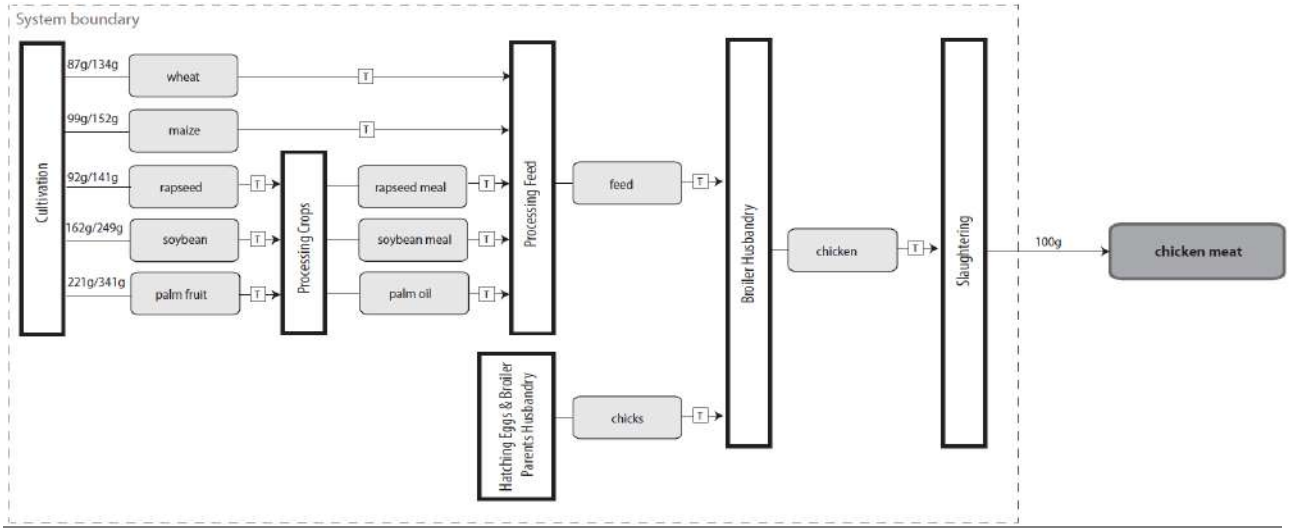


1. This illustration excludes energy supply, side streams along the process chain, food/ingredient losses, auxiliary materials and process and cooling water flows
2. This illustration shows primarily the harvesting mass flows of the crops (wet mass); minor mass flows may be excluded from the illustration
3. The harvesting mass flows shown are total mass flows thus include crop mass required for side streams along the process chain
4. This illustration and the LCA model exclude mass flows omitted based on cut-off criteria (section 2.2. in Deliverable 5.2)

Figure 2-5: Process flow chart of P2F VMA-fiber lentil and amaranth



1. Mass flows divided by forward slash relate to: "LOW" impact scenario /"HIGH" impact scenario
2. This illustration excludes energy supply, side streams along the process chain, food/ingredient losses, auxiliary materials, process and cooling water flows and manure
3. This illustration shows primarily the harvesting mass flows of the crops (wet mass); minor mass flows may be excluded from the illustration
4. The harvesting mass flows shown are total mass flows thus include crop mass required for side streams along the process chain
5. This illustration and the LCA model exclude mass flows omitted based on cut-off criteria (section 2.2. in Deliverable 5.2)

Figure 2-6: Process flow chart of a traditional meat (chicken) product

2.5.2. Flow charts VMA-spread

Figure 2-7 illustrates processes along the value chain as well as mass flow ranges at the crop level for the three examined VMA-spread prototypes.

Figure 2-8 illustrates the corresponding processes along the value chain as well as mass flow ranges at the crop level for the traditional spread reference system Leberwurst (liver paté).

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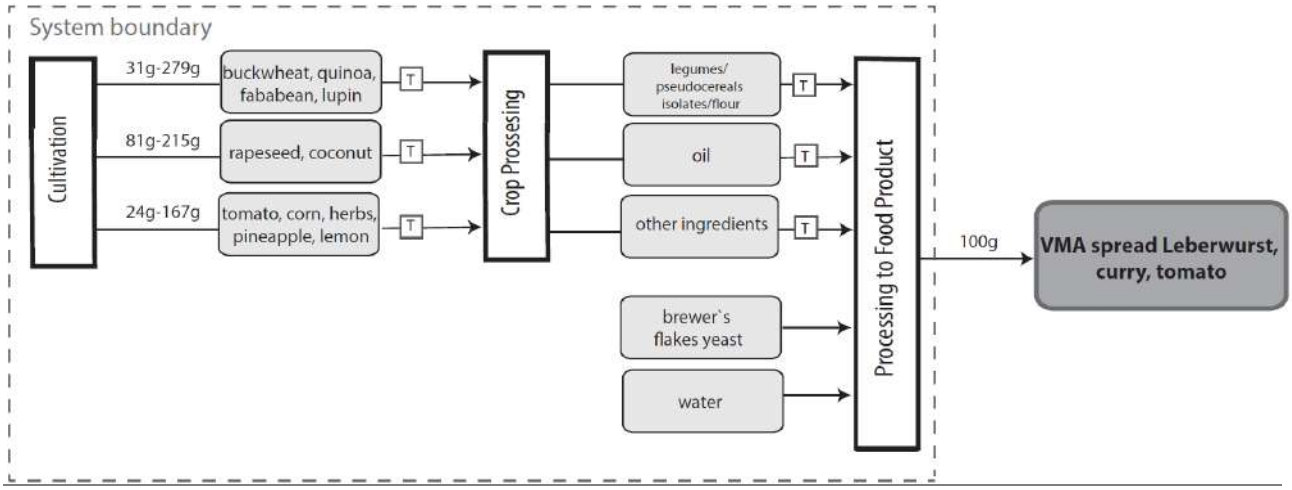
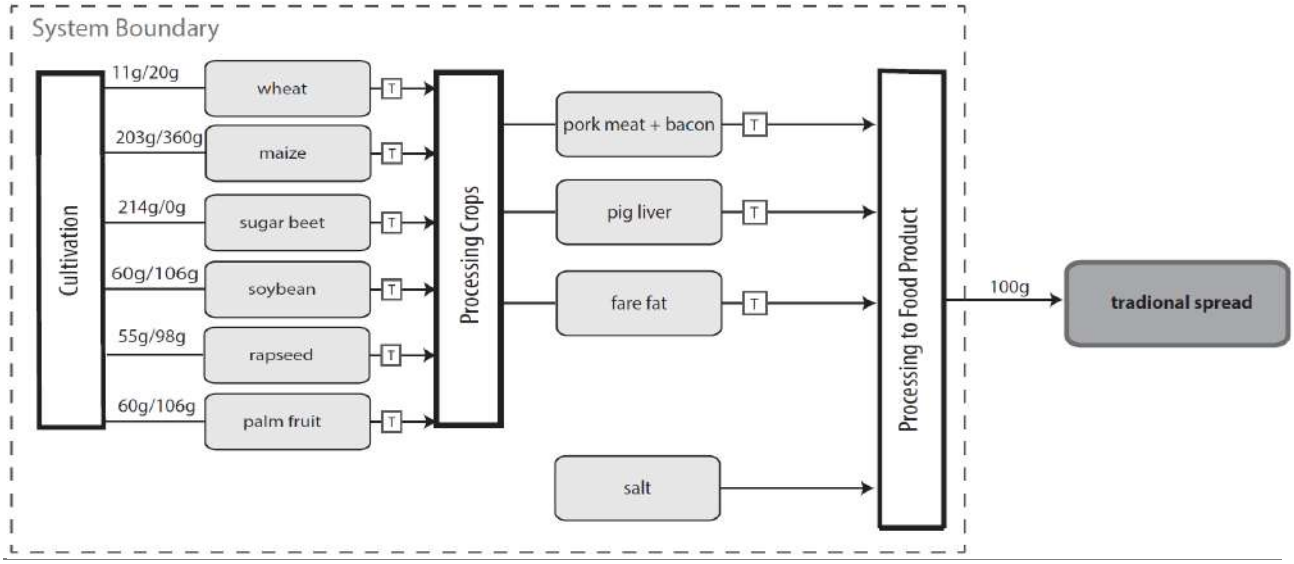


1. This illustration excludes energy supply, side streams along the process chain, food/ingredient losses, auxiliary materials and process and cooling water flows
2. This illustration shows primarily the harvesting mass flows of the crops (wet mass); minor mass flows may be excluded from the illustration
3. The harvesting mass flows shown are total mass flows thus include crop mass required for side streams along the process chain
4. This illustration excludes recipe mixes for confidentiality reasons
5. This illustration and the LCA model exclude mass flows omitted based on cut-off criteria (section 2.2. in Deliverable 5.2)

Figure 2-7: Process flow chart of P2F VMA-spread prototypes type leberwurst, curry and tomato



1. Mass flows divided by forward slash relate to: "LOW" impact scenario/"HIGH" impact scenario
2. This illustration excludes energy supply, side streams along the process chain, food/ingredient losses, auxiliary materials, process and cooling water flows and manure
3. This illustration shows primarily the harvesting mass flows of the crops (wet mass); minor mass flows may be excluded from the illustration
4. The harvesting mass flows shown are total mass flows thus include crop mass required for side streams along the process chain
5. This illustration and the LCA model exclude mass flows omitted based on cut-off criteria (section 2.2. in Deliverable 5.2)

Figure 2-8: Process flow chart of traditional spread Leberwurst (liver paté)

2.5.3. Flow charts vegetable milk

Figure 2-9 illustrates processes along the value chain for the vegetable milk.

Figure 2-10 and Figure 2-11 illustrate the corresponding processes along the value chain as well as mass flow ranges at the crop level for the traditional reference system cow milk and the modern reference system soy milk, respectively.

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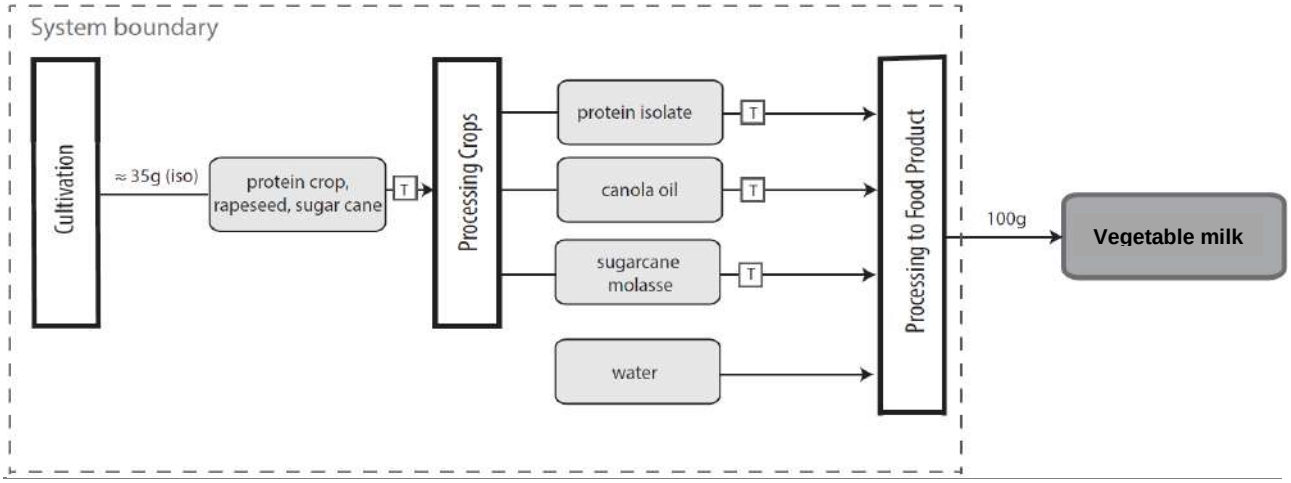
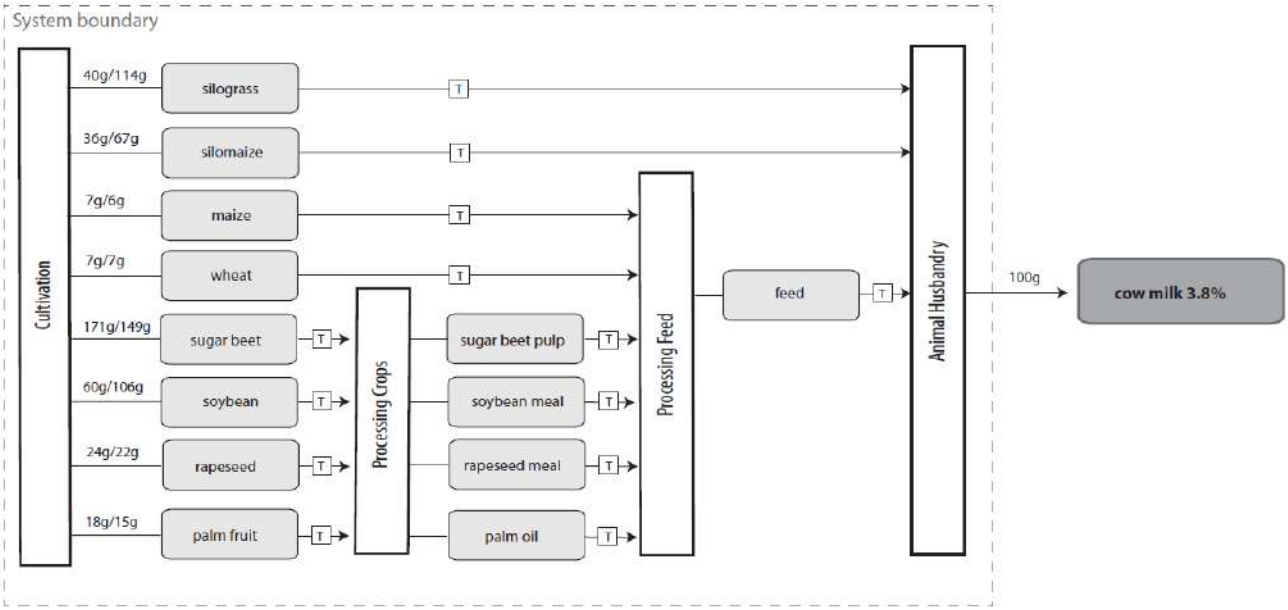


1. This illustration excludes energy supply, side streams along the process chain, food/ingredient losses, auxiliary materials and process and cooling water flows
2. This illustration shows primarily the harvesting mass flows of the crops (wet mass); minor mass flows may be excluded from the illustration
3. The harvesting mass flows shown are total mass flows thus include crop mass required for side streams along the process chain
4. This illustration excludes recipe mixes for confidentiality reasons
5. This illustration and the LCA model exclude mass flows omitted based on cut-off criteria (section 2.2. in Deliverable 5.2)

Figure 2-9: Process flow chart of P2F innovative vegetable milk



1. Mass flows divided by forward slash relate to: "LOW" impact scenario /"HIGH" impact scenario
2. This illustration excludes energy supply, side streams along the process chain, food/ingredient losses, auxiliary materials, process and cooling water flows and manure
3. This illustration shows primarily the harvesting mass flows of the crops (wet mass); minor mass flows may be excluded from the illustration
4. The harvesting mass flows shown are total mass flows thus include crop mass required for side streams along the process chain
5. This illustration and the LCA model exclude mass flows omitted based on cut-off criteria (section 2.2. in Deliverable 5.2)

Figure 2-10: Process flow chart of traditional cow milk

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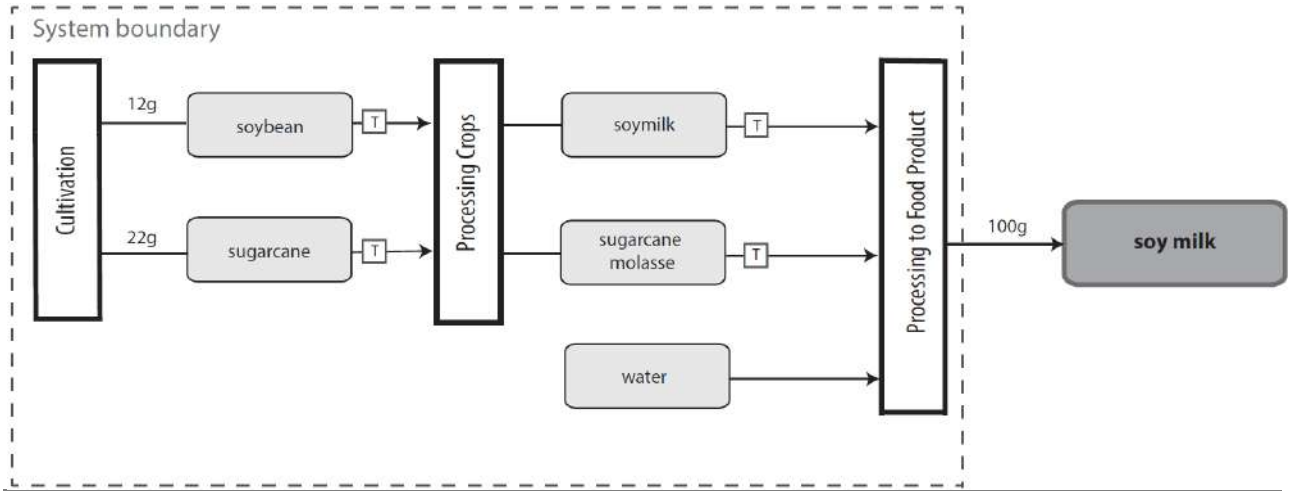
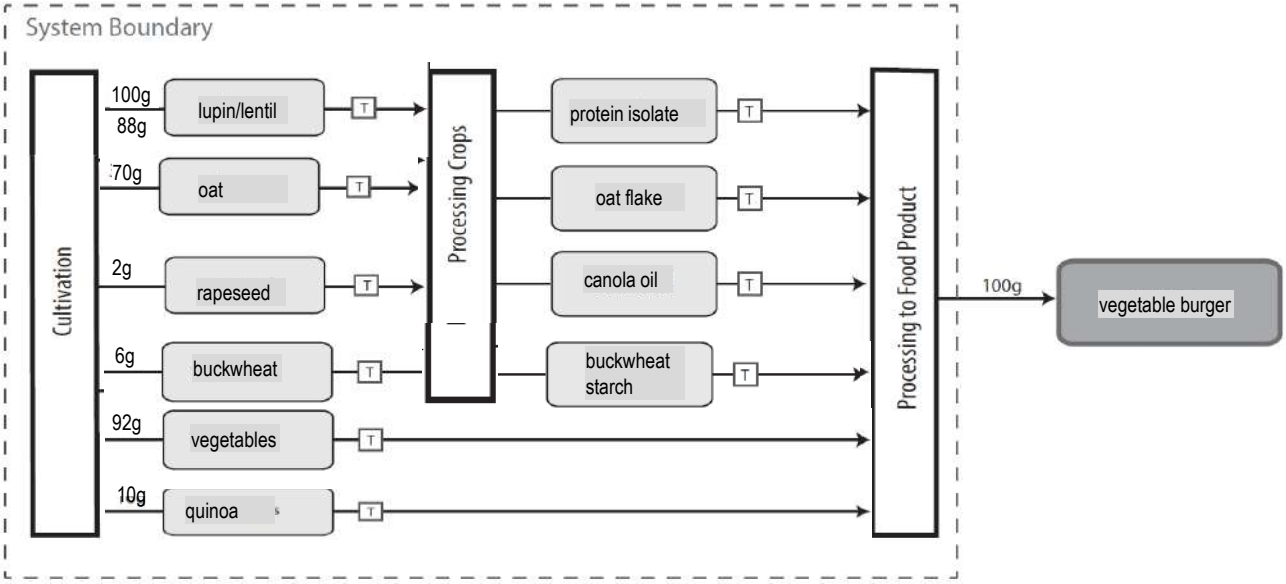


1. This illustration excludes energy supply, side streams along the process chain, food/ingredient losses, auxiliary materials and process and cooling water flows
2. This illustration shows primarily the harvesting mass flows of the crops (wet mass); minor mass flows may be excluded from the illustration
3. The harvesting mass flows shown are total mass flows thus include crop mass required for side streams along the process chain
4. This illustration excludes recipe mixes for confidentiality reasons
5. This illustration and the LCA model exclude mass flows omitted based on cut-off criteria (section 2.2. in Deliverable 5.2)

Figure 2-11: Process flow chart of modern soy milk

2.5.4. Flow charts vegetable burger

Figure 2-12 illustrates processes along the value chain as well as mass flow ranges at the crop level for the examined P2F vegetable burgers based on lupin and lentil protein isolate.



1. This illustration excludes energy supply, side streams along the process chain, food/ingredient losses, auxiliary materials and process and cooling water flows
2. This illustration shows primarily the harvesting mass flows of the crops (wet mass); minor mass flows may be excluded from the illustration
3. The harvesting mass flows shown are total mass flows thus include crop mass required for side streams along the process chain
4. This illustration excludes recipe mixes for confidentiality reasons
5. This illustration and the LCA model exclude mass flows omitted based on cut-off criteria (section 2.2. in Deliverable 5.2)

Figure 2-12: Process flow chart of innovative P2F vegetable burgers based on lentil/lupin protein isolate

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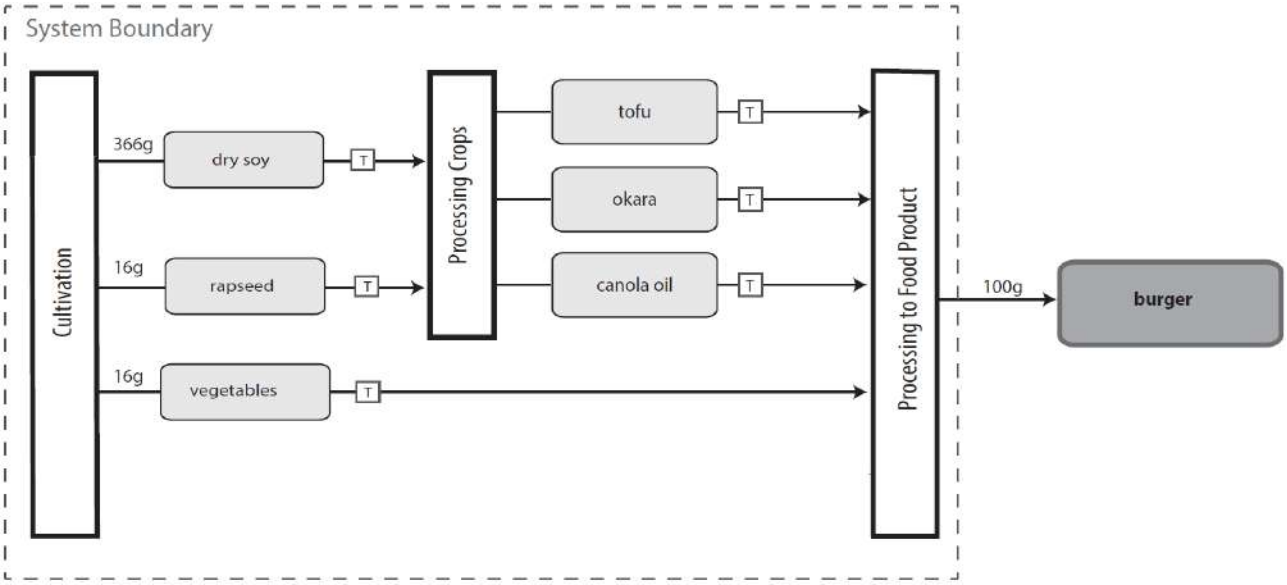
Figure 2-13 and Figure 2-14 illustrate the corresponding processes along the value chain as well as mass flow ranges at the crop level for the modern reference system soy-based burger and the traditional reference system beef burger, respectively.



6. This illustration excludes energy supply, side streams along the process chain, food/ingredient losses, auxiliary materials and process and cooling water flows
7. This illustration shows primarily the harvesting mass flows of the crops (wet mass); minor mass flows may be excluded from the illustration
8. The harvesting mass flows shown are total mass flows thus include crop mass required for side streams along the process chain
9. This illustration excludes recipe mixes for confidentiality reasons
10. This illustration and the LCA model exclude mass flows omitted based on cut-off criteria (section 2.2. in Deliverable 5.2)

Figure 2-13: Process flow chart of a modern soy burger

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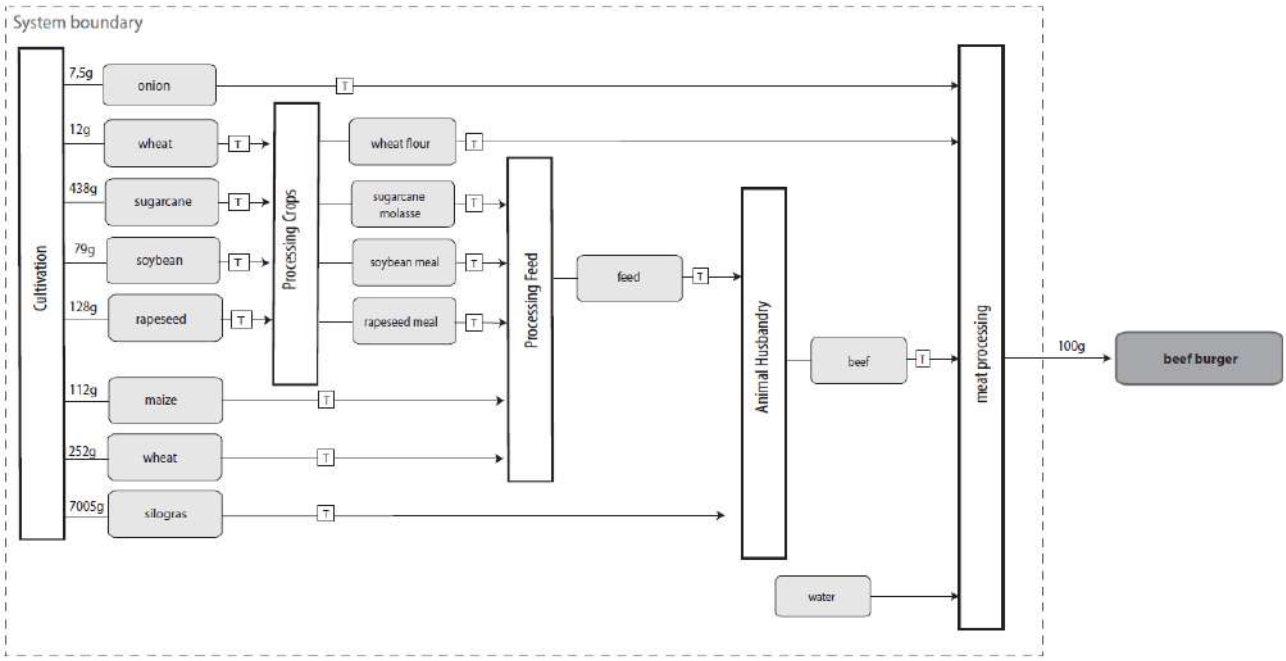

1. Mass flows divided by forward slash relate to: "LOW" impact scenario /"HIGH" impact scenario
2. This illustration excludes energy supply, side streams along the process chain, food/ingredient losses, auxiliary materials, process and cooling water flows and manure
3. This illustration shows primarily the harvesting mass flows of the crops (wet mass); minor mass flows may be excluded from the illustration
4. The harvesting mass flows shown are total mass flows thus include crop mass required for side streams along the process chain
5. This illustration and the LCA model exclude mass flows omitted based on cut-off criteria (section 2.2. in Deliverable 5.2)

Figure 2-14: Process flow chart of a traditional beef burger

2.6. Scenario overview and reference flows

The following table 2-24 provides a scenario overview on all food product groups examined by means of life cycle assessment (LCA) along with the section numbers where corresponding LCA results are to be found.

Please note that for all product groups presented in this main report, results are shown for two alternative functional units – protein-based and mass-based. (For more detailed information on selection of functional units, please see Deliverable D5.2 section 2.3). Corresponding reference flows of examined food products depending on the choice of functional units are documented in tables 2-25 to 2-28. Results for both functional units are presented in sections 3.2 (protein-based) and section 3.3 (mass-based), respectively.

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Table 2-24: Scenario overview – innovative P2F food products and their traditional and modern reference counterparts

Product group	Subgroup	Shortname	Main ingredients	Results in sections
VMA-fiber	innovative	VMA-fiber AF LuPI	Lupin protein isolate, amaranth flour	3.1.1, 3.2.1, 3.3.1
		VMA-fiber BWF LuPI	Lupin protein isolate, buckwheat flour	3.1.1, 3.2.1, 3.3.1
		VMA-fiber AF LePI	Lentil protein isolate, buckwheat flour	3.1.1, 3.2.1, 3.3.1
		VMA-fiber BWF LePI	Lentil protein isolate, buckwheat flour	3.1.1, 3.2.1, 3.3.1
	traditional	Chicken low impact	Chicken meat (low FCR*)	3.1.1, 3.2.1, 3.3.1
		Chicken high impact	Chicken meat (high FCR*)	3.1.1, 3.2.1, 3.3.1
VMA-spread	innovative	VMA-spread type Leberwurst	Lupin protein isolate, legume or pseudocereal flour, vegetable oil	3.1.2, 3.2.2, 3.3.2
		VMA-spread type Tomato	Lupin protein isolate, legume or pseudocereal flour, vegetable oil	3.1.2, 3.2.2, 3.3.2
		VMA-spread type Curry	Lupin protein isolate, legume or pseudocereal flour, vegetable oil	3.1.2, 3.2.2, 3.3.2
	traditional	Leberwurst (liver paté) low impact	Pork-based spread (low FCR*)	3.1.2, 3.2.2, 3.3.2
	traditional	Leberwurst (liver paté) high impact	Pork-based spread (high FCR*)	3.1.2, 3.2.2, 3.3.2
Vegetable milk	innovative	Vegetable milk	Legume protein isolate, vegetable oil, sugar	3.1.3, 3.2.3, 3.3.3
	traditional	Cow milk low impact	Cow milk (low FCR*)	3.1.3, 3.2.3, 3.3.3
	traditional	Cow milk high impact	Cow milk (high FCR*)	3.1.3, 3.2.3, 3.3.3
	modern	Soy milk	European soybean, sugar	3.1.3, 3.2.3, 3.3.3
Vegetable burger	innovative	Vegetable burger lupin	Lupin protein isolate, oat flakes, pseudocereal, buckwheat starch, other vegetables, vegetable oil	3.1.4, 3.2.4, 3.3.4

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	innovative	Vegetable burger lentil	Lentil protein isolate, oat flakes, pseudocereal, buckwheat starch, other vegetables, vegetable oil	3.1.4, 3.2.4, 3.3.4
Vegetable burger (continued)	traditional	Beef burger	Beef, onion, wheat	3.1.4, 3.2.4, 3.3.4
	modern	Soy burger	Tofu and okara based on European soybean, other vegetables, vegetable oil	3.1.4, 3.2.4, 3.3.4
Vegetable pasta	innovative	Vegetable pasta	Wheat, buckwheat flour, faba bean flour, lupin protein isolate	Appendix
	traditional	Egg pasta	Semolina, fresh egg (low FCR*), vegetable oil	Appendix
	traditional	Egg pasta	Semolina, fresh egg (high FCR*), vegetable oil	Appendix
Protein-rich Bread	innovative	Protein-rich bread	Wheat, legume/pseudocereal flour, vegetable oil, lupin protein isolate	Appendix
	traditional	Bread	Wheat flour	Appendix

*FCR: Feed conversion ratio, for information regarding “high impact and “low impact” scenarios see also section 2.3

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Table 2-25: Comparison of FUs, VMA-fiber and reference systems

Reference flow of food product / Functional Units	Innovative: VMA-fiber	Traditional: Chicken meat
Protein content (30 g) *	100 g (~300 g protein/kg)	140.2 g (~214 g protein/kg)
Mass (100 g)	100 g	100 g

Table 2-26: Comparison of FUs, VMA-spread and reference systems

Reference flow of food product / Functional Units	Innovative: VMA-spread "leberwurst"	Innovative: VMA-spread "tomato"	Innovative: VMA-spread "curry"	Traditional: pork-based Leberwurst
Protein content (12.5 g) *	100 g (~125 g protein/kg)	88.7 g (~141 g protein/kg)	97.7 g (~128 g protein/kg)	83.3 g (~150 g protein/kg)
Mass (100 g)	100 g	100 g	100 g	100 g

Table 2-27: Comparison of FUs, vegetable milk and reference systems

Reference flow of food product / Functional Units	Innovative: vegetable milk	Modern: soy milk	Traditional: cow milk
Protein content (3.3 g) *	100 g (~33 g protein/kg)	100 g (~33 g protein/kg)	100 g (~33 g protein/kg)
Mass (100 g)	100 g	100 g	100 g

Table 2-28: Comparison of FUs, vegetable burger and reference systems

Reference flow of food product / Functional Units	Innovative: lupin burger	Innovative: lentil burger	Modern: soy burger	Traditional: beef burger
Protein content (12.2 g) *	100 g (~122 g protein/kg)	108 g (~113 g protein/kg)	90 g (~136 g protein/kg)	97.1 g (~140 g protein/kg)
Mass (100 g)	100 g	100 g	100 g	100 g

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3. Results

This chapter presents the life cycle assessment results of main examined prototypes. Further results, related to pasta and bread prototypes, are documented in the appendix. Results are presented based on indicators selected for environmental impact assessment as described in Deliverable 5.2 sections 2.4 and 2.6. Additional aspects, related to biodiversity and water assessment, are documented in chapter 4. For information what is behind "low impact" and "high impact" scenarios please see section 2.3. An overall scenario overview is also given in section 2.6.

Section 3.1 illustrates all LCA results in sectoral „stacked bar" format, in order to allow a detailed understanding of system results including identification of main contributing life cycle stages for each food product system. At the beginning of section 3.1, there is an introduction into how to read the stacked bar result format and what is behind the individual life cycle steps shown in that format.

Section 3.2 illustrates all net results transferred into a relative format, thus comparison between examined products is facilitated and several indicators can be shown in one chart, relative to one system used as "benchmark". This is a more condensed result format that facilitates understanding of the overall picture of LCA results also with a comparative focus. All results in section 3.2 refer to the protein-based comparison of innovative prototypes with traditional and modern counterparts ("functional unit: protein").

Section 3.3 illustrates net results again in the condensed relative result format like section 3.2, but all results shown in section 3.3. refer to the mass-based comparison of innovative prototypes with traditional and modern counterparts ("functional unit: mass").

The following paragraphs contain some supplemental background information intended for facilitating the understanding of some indicator's results that will follow throughout this chapter.

<u>General remarks regarding specific indicators examined for P2F prototype food products:</u>

All food products examined here generally show a high relevance of the cultivation phase for both innovative and traditional animal-based products – either as plant-based ingredient or as feed crop for animal-based ingredients. One of the key crop-specific (and also geography-specific) agricultural characteristics is the crop yield which proves to be decisive for several indicators that are part of the environmental performance portfolio.

First, this is directly the case for the indicator *land use*. Low yield crops intrinsically require more land for the cultivation of a given amount of crop than high-yield crops.

Second, the demand of *phosphate rock (CRD)* is primarily specified as an area-based input into the agricultural system. If now a lower yield crop does require more area for cultivation, it is also associated with a higher phosphate rock demand

Furthermore, both cultivation of food or feed crops and animal husbandry are important compartments of nitrogen cycles in the environment. Specifically, ammonia and laughing gas emissions to air as well as nitrate emissions to water are to be named here.

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Several environmental indicators show a strong influence of such nitrogen emissions (e.g. laughing gas is an important *greenhouse gas*, ammonia contributes to *terrestrial eutrophication* and *acidification*, and nitrate emissions to water are often the most important contributor to *aquatic eutrophication* in the assessment of agriculture-based food). For this reason, quantification of those nitrogen-bound emissions is quite relevant for the environmental assessment of examined food products. Consequently in this project, with the SQCB nitrate model being applied, a nitrate emission model was selected that takes into account important geography-specific as well as crop-specific cultivation phase characteristics such as precipitation and soil properties (clay content) as well as crop-specific nitrogen uptake and rooting depth. Also the SQCB model is of universal applicability, as it is not restricted to a certain geographic area.

One characteristic of the selected SQCB model is the fact that the model is an area-based emission regression model, which means that nitrate emissions are primarily calculated on a "per ha" basis. To give an example, legume crops that fix nitrogen from the atmosphere into their biomass during the growth phase typically show lower nitrate leaching on a "per ha" basis than e.g. typical feed crops (e.g. maize and wheat). On the other hand, LCA results are presented on a "per food product" basis (quantified either by protein or mass). In between those two lines of reference is the parameter of agricultural yield, both for feed and food crops. In other words, if an area-based nitrate emission is combined with a relatively low yield-crop, it may lead to specifically higher nitrate emissions on a product basis than if combined with a very high-yield (e.g. traditional feed) crop.

3.1. Results in sectoral format

The following charts illustrate the sectoral results, expressed in equivalents per FU (e.g. 30g protein). Each examined food product system is divided into three columns. The first bar (stacked bar) shows the environmental burdens grouped by the contributions by different life cycle steps (e.g. transportation, processing to final product, etc.). The second bar (green) represents credits that are taken into account by replaced N-fertilizer ("negative burdens") due to air nitrogen fixation by legumes or manure nitrogen that lead to reduced mineral N fertilizer demand for subsequent crops as part of the crop rotation system. The third bar (grey) shows the net results, i.e. the result of the mathematical subtraction of credits from burdens. The following paragraph provides some details regarding which processes are grouped into which life cycle step as shown in the sectoral bar charts.

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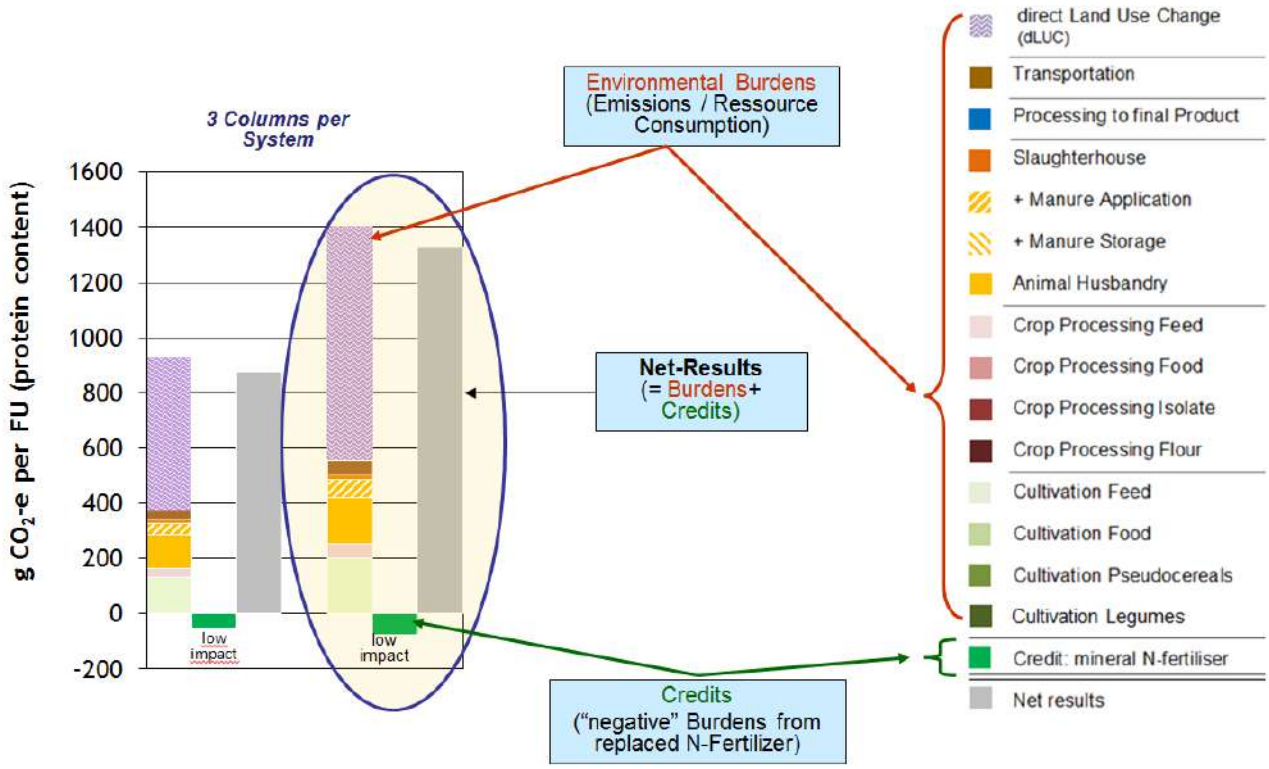

Figure 3-1: reading aid for sectoral charts, example indicator: Climate Change (with dLUC)

Contributions of the following individual life cycle steps are shown in sectoral (stacked) bar charts:

- Cultivation of lupin, lentil and faba bean (**'Cultivation Legumes**')
- Cultivation of quinoa and amaranth ('**Cultivation Pseudocereals**)
- Cultivation of non-P2F crops as further ingredients, such as European soybean for food use, rapeseed, carrot, onion, oat ('**Cultivation Food**')
- Cultivation of feed crops for animal-based ingredients, such as Brazilian soybean, Wheat, Maize, Sugarbeet ('**Cultivation Feed**')
- Processing of seeds into flour, e.g.sorting, dehulling, milling, if applicable airjet classification ('**Crop Processing Flour**')
- Isolation of seed protein including the various sub-processes, such as dehulling, protein precipitation up to spray-drying ('**Crop Processing Isolate**')
- Processing of other crops into food ingredients, such as oilseed milling, production of oat flakes('**Crop Processing Food**')
- Processing of feed crops into feed components, such as oilseed milling in order to obtain soymeal/rapemeal for feed purposes ('**Crop Processing Feed**')
- Energy requirements for stables, manure handling within stables, and animal-related emissions directly from the stables ('**Animal Husbandry**')

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- Emissions generated during storage of animal manure ('**Manure Storage**')
- Emissions released if manure is applied on agricultural fields ('**Manure Applicationl**')
- Energy requirements for slaughterhouse handling, heating and cooling purposes ('**Slaughterhouse**')
- Production of the final food product out of the ingredients, e.g. burger production or extrusion of protein isolate ('**Processing to final product**')
- Transport of all food ingredients and their raw materials to each of the processing steps as well as the to the final food production ('**Transportation**')
- CO_2 emissions related to crop cultivation on fields that have undergone a direct land use change ('**direct land use change dLUC**')
- Nitrogen that is available for other crops (outside of the examined food products and feed crop cultivation), due to nitrogen fixed by legumes and available on the field for subsequent crops, or from animal manure, is taken into account by means of a credit. It is assumed that a mineral N fertilizer is replaced. This is shown as ('**Credit: mineral N fertilizer**')

3.1.1. VMA-fiber (sectoral)

The following figures (Figure 3-2 to Figure 3-5) illustrate sectoral results of VMA-fiber product group.

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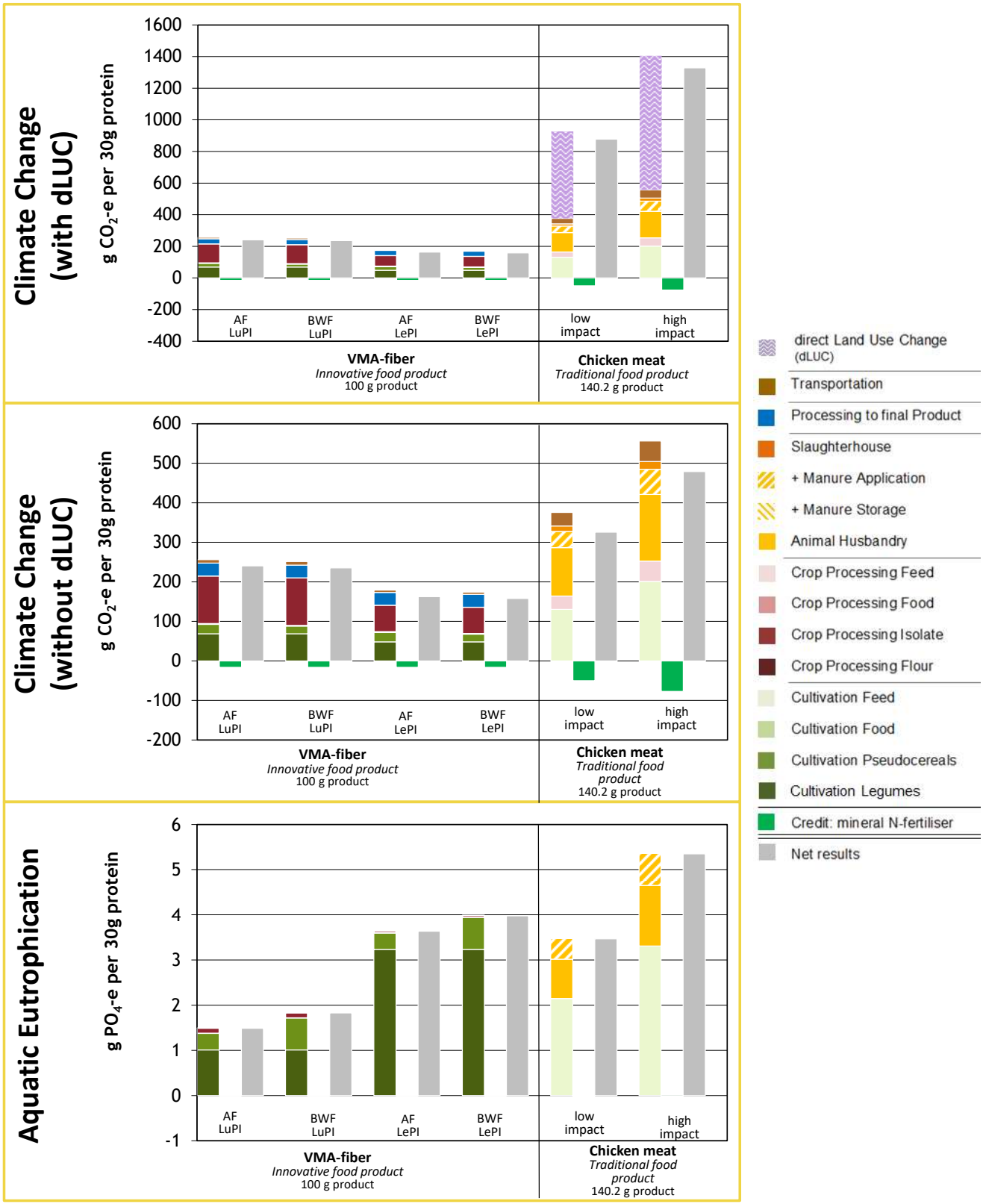

Figure 3-2: sectoral results of VMA-fiber, indicators: Climate Change (with and without dLUC), and Aquatic Eutrophication (VMA: vegetable meat alternative, AF: amaranth flour, BWF: buckwheat flour, LuPI: lupin protein isolate, LePI: lentil protein isolate)

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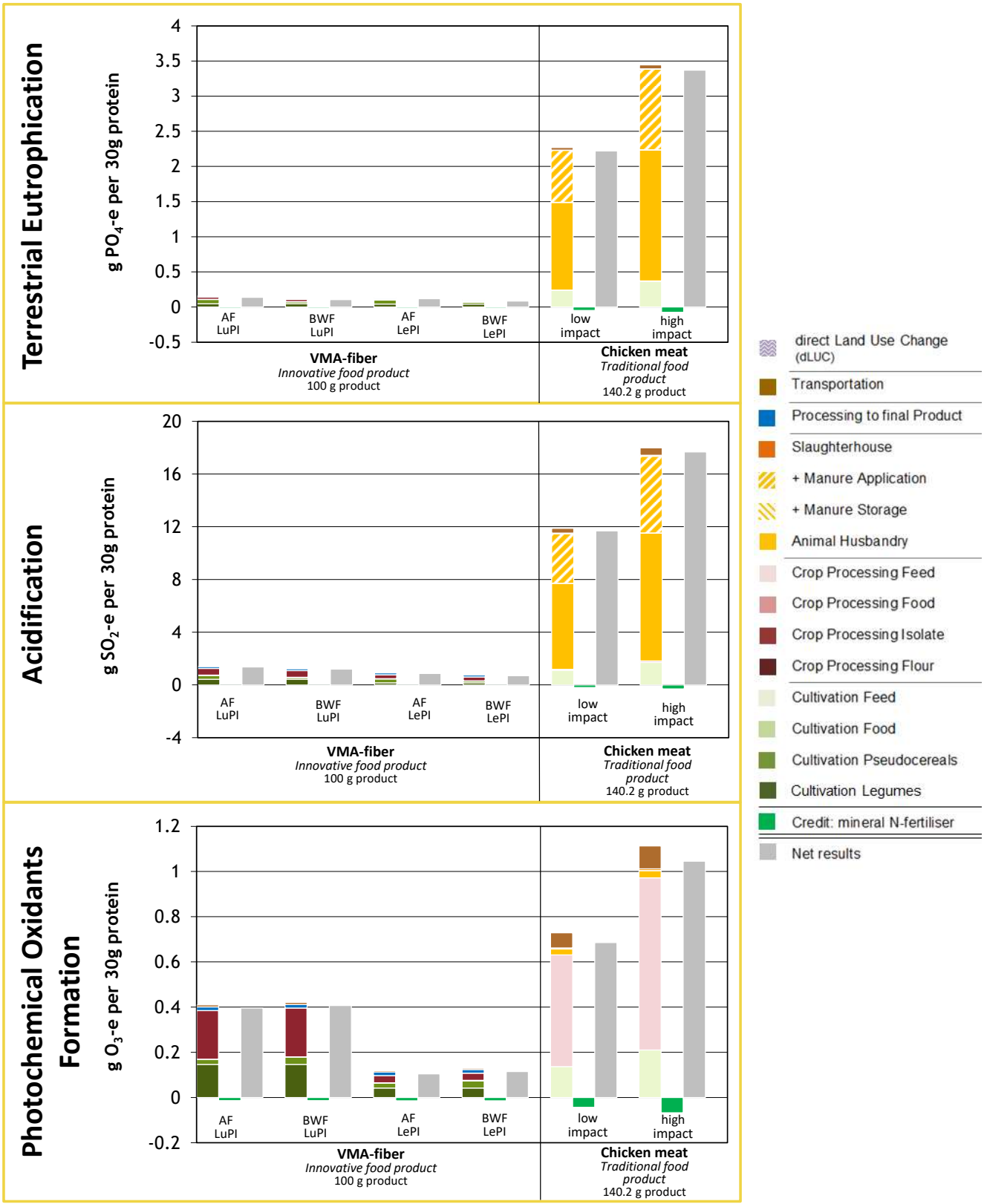

Figure 3-3: sectoral results of VMA-fiber, indicators: Terrestrial Eutrophication, Acidification, and Photochemical Oxidants Formation (VMA: vegetable meat alternative, AF: amaranth flour, BWF: buckwheat flour, LuPI: lupin protein isolate, LePI: lentil protein isolate)

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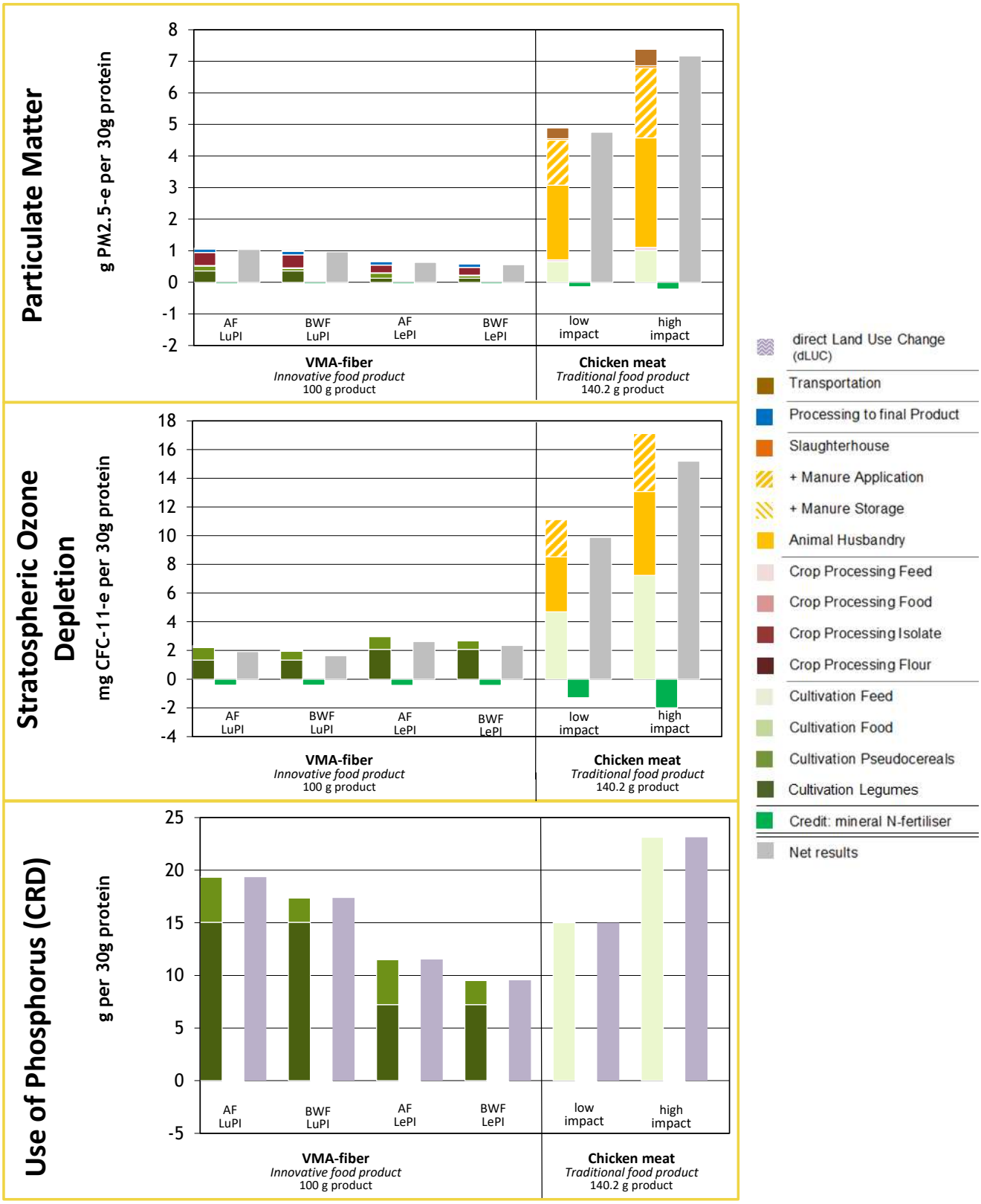

Figure 3-4: sectoral results of VMA-fiber, indicators: Particulate Matter, Stratospheric Ozone Depletion, and Phosphate Rock (CRD) (VMA: vegetable meat alternative, AF: amaranth flour, BWF: buckwheat flour, LuPI: lupin protein isolate, LePI: lentil protein isolate, CRD: cumulative resource demand)

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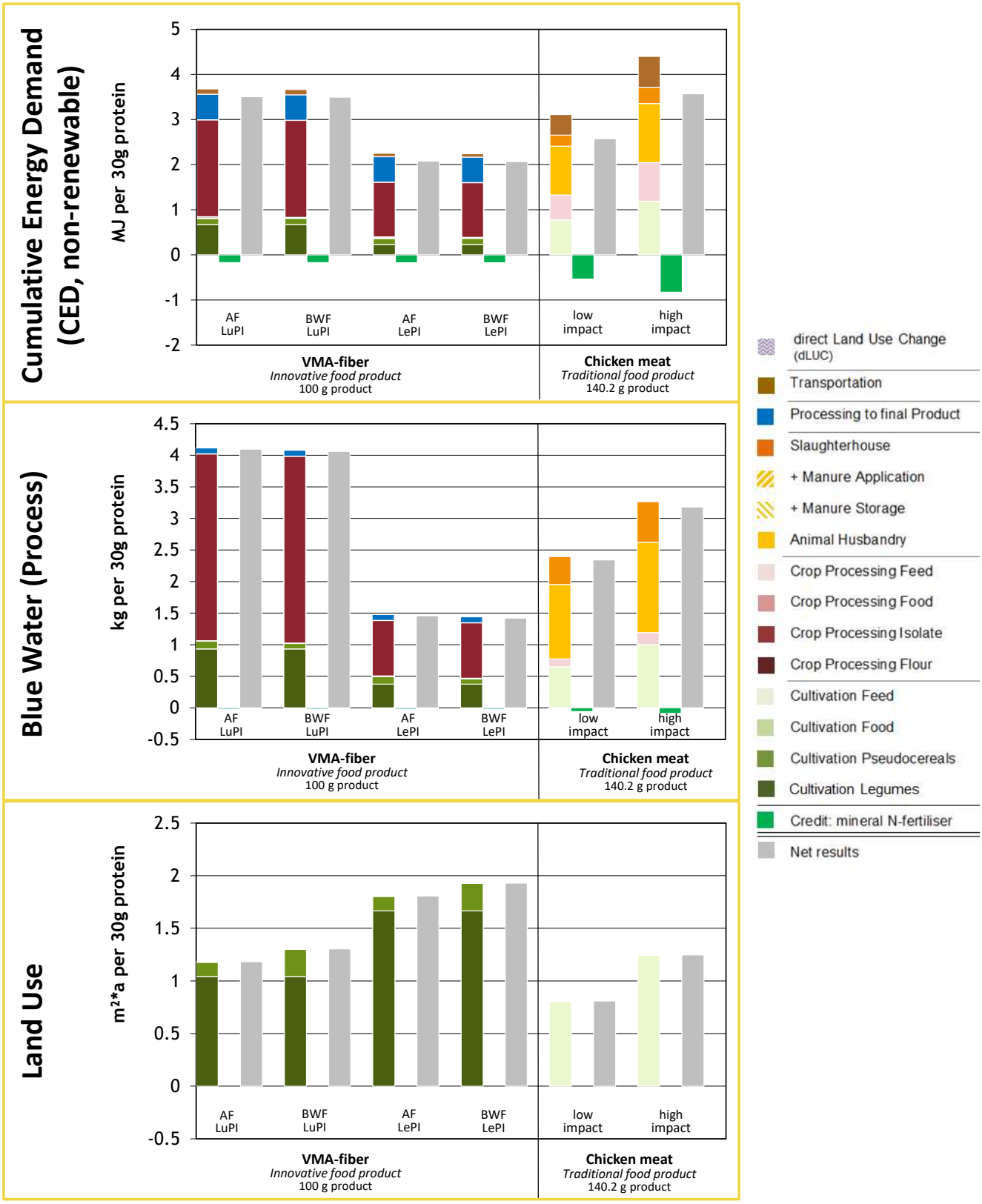

Figure 3-5: sectoral results of VMA-fiber, indicators: Cumulative Energy Demand (CED, non-renewable), Blue Water (Process), Land Use (VMA: vegetable meat alternative, AF: amaranth flour, BWF: buckwheat flour, LuPI: lupin protein isolate, LePI: lentil protein isolate)

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Climate Change (with and without dLUC)

P2F prototypes: VMA-fiber

The climate change results for the innovative fiber products within this study are composed of the greenhouse gas emissions associated with certain life cycle steps for each product. For instance, the stage of crop processing for protein isolate production for the four VMA-fiber products contributes the greatest amounts of greenhouse gases. If we use the amaranth flour lupin isolate VMA-fiber as an example, 47 % of the greenhouse gas emissions are released during this phase, of which the main contributing gases are carbon dioxide, methane, and nitrous oxide at 92 %, 5 %, and 1 % of the greenhouse gas emissions, respectively. Those are related to processing energy along the value chain for a good part. This crop processing stage for protein isolate includes the processes of drying and sorting, de-hulling and milling of seeds as well as the several protein extraction stages, among others.

Other processes which are associated with greenhouse gas emissions include the cultivation of the lupin legume (27 % of emissions in the case of the amaranth flour lupin isolate VMA-fiber) and the processing to the final product (13 % of emissions in the case of the amaranth flour lupin VMA-fiber). Two thirds of the greenhouse gas emissions of legume cultivation can be attributed primarily to CO_2-emissions from field work and manufacturing of fertilizers and one-third can be attributed to the release of N_2O from plant residue material.

The VMA-fiber products which use lupins rather than lentils create a larger climate change potential. This is for a good part related to the difference in processing pathways, as e.g. lentils do not need a de-oiling step, their protein yield per seed input is higher than for lupins. Consequently, lentil-based VMA-fiber products need a considerably lower seed mass input per product than lupin-based VMA-fiber products do.

Reference product: traditional chicken meat

The results regarding climate change for chicken meat production are dominated by greenhouse gas emissions from the cultivation of chicken feed, the animal husbandry processes, and manure application if we look at the direct effects from the chicken meat system. The feed crop cultivation phase includes the production of feed crops rapeseed, soybean, wheat, maize, and oil palm, during which nitrous oxide, carbon dioxide, and methane are released. This phase generates the most greenhouse gas emissions e.g. ~ 35 % in the case of low-impact chicken production (excluding dLUC).

If furthermore direct land use change impacts[6] are taken into account, related greenhouse gas emissions are even the main contributor to the overall potential impact on climate change. The land use change impacts are directly related to the feed, in this case due to Brazilian soybean and Malaysian oil palm cultivation.

The animal husbandry phase releases around 33 % of the total greenhouse gas emissions (excluding dLUC), primarily due to the energy, feed, and water needed for the housing and keeping of chickens. Nitrous oxide emissions make up 54 % of the animal husbandry greenhouse gases, while carbon dioxide and methane contribute 40 % and 6 % respectively.

[6] As stated in section 2.5.1.5 in Deliverable 5.2

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In addition, approximately 8 % of the greenhouse gas emissions related to climate change (excluding dLUC) are created from the application of manure and from the slaughterhouse. Manure application considers the spreading of manure and the emissions released from the manure itself. 100 % of the emissions from this phase are nitrous oxide, which is a release of a part of the nitrogen that is excreted by the broilers. On the other hand, the majority (95 %) of the emissions from the slaughterhouse are carbon dioxide, which are mostly related to the energy demand e.g. for cooling and processing in the slaughterhouse.

Credits are associated with the chicken meat scenarios due to the application of manure as N fertilizer. Both aspects may reduce the mineral N-fertilizer requirements for subsequent crops (as part of the crop rotation).

Comparison between systems

It is clearly visible that the greatest difference in climate change potential between the innovative food products in comparison to the traditional products is the application of manure and animal husbandry required for chicken production. If land use change effects are taken into account for typical feed components, such as soy meal and palm kernel, related greenhouse gas emissions even double for the chicken meat. Hence the net difference between traditional (chicken meat) and innovative food products (VMA-fiber) can grow even larger. The cultivation of the feed for chickens in addition to the energy required for the husbandry of chicken create more greenhouse gas emissions than the innovative products. However, it is still worth noting that the innovative products require more processing to the final production, which creates its own greenhouse gas emissions which are not produced for the traditional chicken meat.

Aquatic Eutrophication

P2F prototypes: VMA-fiber

Aquatic eutrophication potential for the VMA-fiber products is primarily caused by the cultivation of legumes (81 % of PO_4-equivalent emissions for the buckwheat lentil protein isolate fiber product). This is caused by nitrate leaching from either plant residues or from the soil nitrogen pool (as lentils and lupins are legumes and do not require nitrogen fertilization). The high relevance of the lentil is related to the fact that lentils are the main ingredient material within the VMA-fiber product. Also the effect of yield differences (lentil 0.8 t/ha, lupin 2.5 t/ha, wheat 7.8 t/ha, maize 9.7 t/ha) becomes clearly apparent within the aquatic eutrophication results: Although eutrophication potentials for lentils are clearly lower on a per ha basis for lentil cultivation than for typical feed crops (wheat, maize etc.), this pattern disappears in the comparison of lentil-based VMA-fiber versus chicken meat on a product basis (in this case based on a comparable amount of protein).

Most of the emissions which lead to aquatic eutrophication potential are nitrogen compounds, such as nitrate, which leaches through the soil towards groundwater during phases of cultivation. In the case of the buckwheat flour lentil protein isolate fiber product, 93 % of the PO4-equivalent emissions for the process of legume cultivation are nitrogen compounds. The difference in PO4-equivalent emissions between the lupin and lentil products is due to the fact that lupin has the ability to use twice as much nitrogen from the soil as lentil, therefore avoiding potential nitrogen leaching and reducing aquatic eutrophication potential. However it has to be kept in mind that this effect is closely related to the yields (with the lentil (~0.8 t/ha) being considerably lower than lupin (~2.5 t/ha)).

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Pseudocereal cultivation creates the second-largest amount of PO4-equivalent emissions for VMA-fiber products, however relatively small at just 18 % of the equivalent emissions, in the case of the buckwheat lentil protein isolate emissions. Similar to legume cultivation, the products which use buckwheat as the pseudocereal have a slightly higher aquatic eutrophication potential than the products with amaranth due to the difference in nitrogen uptake ability. Both amaranth and buckwheat production in the EU cultivation models include the application of N-fertilizer; however, amaranth produces higher yields per ha than buckwheat and therefore can take up more nitrogen per ha.

Reference product: traditional chicken meat

The aquatic eutrophication potential created by chicken meat production is largely caused by the processes involved in feed cultivation. The chicken feed is a mixture of barley, oat, wheat, maize, sunflower, soybean, rapeseed, and palm kernel (see section 2.3.1). Each of these crops is cultivated using different amounts of mineral fertilizers. This is relevant for the aquatic eutrophication potential because, as with the VMA-fiber products, the majority of eutrifying emissions are Nitrogen compoundssuch as nitrate and nitrite. Nitrate leaching from the use of mineral N-fertilizer here leads to higher potential for aquatic eutrophication.

Chicken meat production also creates the potential for aquatic eutrophication via the animal husbandry practices (24 % in the case of the low-impact chicken meat). Nitrogen compounds are again the largest amount of PO4 equivalent emissions and originate from the nitrogen excreted by the broilers.

Manure application is the third largest contributor to aquatic eutrophication potential at 13 % for the low-impact chicken meat. This is due to the nitrate leaching potential of the applied manure for feed cultivation due to the nitrogen excreted with the manure by the animal.

Comparison between systems

Aquatic eutrophication potential is primarily composed of nitrate as PO4-equivalents. These Nitrogen compounds are formed from nitrogen sources in the feed and food crop cultivation (plant residues, soil nitrogen pool as well as mineral nitrogen fertilizer applications), as well as from the nitrogen excreted in the chicken husbandry phase of chicken meat production. While the innovative products create aquatic eutrophication potential through the crop cultivation, the potential created by the high-impact traditional chicken meat is almost always greater due to the high demand for feed for the chickens, which use nitrogen fertilizer during the cultivation and the nitrogen excreted during the animal husbandry phase which can leach into the groundwater and cause aquatic eutrophication. Low yields of the P2F crop lentil leads to slightly higher results than the low-impact chicken meat product, whereas the lupin-based innovative product causes only half the aquatic eutrophication potential than the low-impact traditional product.

Terrestrial Eutrophication, Acidification, and Particulate Matter

P2F prototypes: VMA-fiber

The categories of terrestrial eutrophication, acidification, and particulate matter from the production of innovative VMA-fiber products have similar result patterns regarding main contributing life cycle steps. The impact potentials are created relatively homogeneously from the production phases of legume and pseudocereal cultivation and crop processing of the protein

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isolate. Ammonia, nitrous oxide, and nitrogen dioxide are the gasses which contribute to terrestrial eutrophication potential and originate from the cultivation practices and cultivation prechains for legumes and pseudocereals. The direct field emissions include nitrogen emissions to air from mineral fertilizer and, in case of legumes, the release of N_2O from plant residue material. Furthermore, eutrophying gases are released during fuel combustion for mineral fertilizer and pesticide production as well as agricultural machine operation. The acidification potential is most influenced by the sulfur oxide released from the production of mineral fertilizer used in the cultivation of the crops, as well as the nitrogen oxides from the agricultural machine use and the drying and storage of the crops after harvest. Similarly, secondary sulfur oxide particles produced from the energy processes required for the protein isolates contributes the greatest amount of PM 2.5-equivalents towards the particulate matter potential.

Reference product: traditional chicken meat

The emissions that contribute to terrestrial eutrophication, acidification, and particulate matter formation in regards to chicken meat production result primarily from the animal husbandry phase: 55 %, 53 %, and 50 % respectively. Relevant ammonia emissions are associated with the chicken husbandry phase as a result of nitrogen required by the animals from the feed, incorporated into the body and partly excreted and thus forming a nitrogen pool in the excrements. Manure application contributes the second-highest amount of emissions linked to terrestrial eutrophication, acidification, and particulate matter potential: 32 %, 33 %, and 30 %, respectively. Similar to the animal husbandry phase, the main emission released from manure is ammonia.

Comparison between systems

Chicken meat production has a greater potential to cause terrestrial eutrophication, acidification, and particulate matter formation when compared with the innovative VMA-fiber products. This result is due to the direct effect of animal husbandry practices (associated with high nitrogen requirements) and subsequent manure application, as both activities are not required for innovative VMA-fiber products.

Photochemical-Ozone Formation

P2F prototypes: VMA-fiber

The stages of protein isolate extraction and legume cultivation are the main production stages of the VMA-fiber products which lead to photochemical-ozone formation potential. This is related to the emission of non-methane volatile organic compounds to air. Those emissions are created from several combustion processes, for a good part due to diesel-driven field machinery in case of legume and pseudocereal cultivation.

As far as lupin protein isolate extraction is concerned, the photochemical-ozone formation potential is related to hexane emissions from the solvent extraction process with hexane, the production of chemicals (hexane, hydrogen chloride and sodium hydroxide) and the generation of energy (electricity and heat).

In the case of lentil protein isolate products, about 35 % of the processing emissions come from the production of chemicals (hydrogen chloride and sodium hydroxide) and about 65 % from the generation of energy (electricity and heat). Here again, fuel combustion processes are associated with non-methane volatile organic compound emissions.

Reference product: traditional chicken meat

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Chicken meat production has a relatively higher potential for photochemical-ozone formation than the innovative counterparts. Most of the emissions contributing to the higher potential of photochemical-ozone formation (72 %) are the result of the feed crop processing stage. Specifically, the solvent extraction processes of oils with hexane emit the non-methane volatile organic compound hexane, which is responsible for more than 90 % of the photochemical-ozone formation potential in this sector.

The second highest contributor (20 %) to photochemical-ozone formation potential is the phase of feed crop cultivation, which emits non-methane volatile organic compounds, e.g. through the energy required in the production of mineral fertilizers, or fuel combustion from machine use. These emissions are highest from the feed crops wheat and soybean: wheat requires the most mineral fertilizers and soybean the most machine use per functional unit when compared to the other feed crops due to yield differences.

Comparison between systems

Chicken meat production has a greater potential to cause photochemical-ozone formation when compared with the innovative VMA-fiber products. This result is due to feed crop processing and oversea transports of the feed components palm oil and soybean meal.

Stratospheric Ozone Depletion

P2F prototypes: VMA-fiber

The potential stratospheric ozone depletion produced from 100 g of VMA-fiber product is a result of the emissions created during the cultivation of legumes and pseudocereals. In the case of the amaranth flour lentil protein isolate product, up to 69 % of the emissions are created from the cultivation of legumes and up to 28 % are created from the cultivation of pseudocereals. For pseudocereals, the contributing gas is nitrous oxide associated with the use of mineral fertilizers. For legumes, it is related to the nitrogen released as nitrous oxide from plant residue material. A small credit is given to the VMA-fiber system due to the nitrogen fixing properties of the lupins and lentils used in these products which is expected to lead to a reduction of mineral N-fertilizer required during cultivation of (after-legume) subsequent crops in the crop rotation.

Reference product: traditional chicken meat

The stages of chicken meat production which result in stratospheric ozone depletion potential include the stage of feed cultivation, the animal husbandry stage, and the manure application. In all stages, the main contributing emission is nitrous oxide, which is produced in the largest amounts through the use of manure in the manure application and feed cultivation stages. The phase of feed cultivation considers production of feed crops rapeseed, soybean, wheat, maize, and oil palm. In the case of low impact chicken meat production, the cultivation of chicken feed produces up to 43 % of the total stratospheric ozone depletion potential per 140.2 g of product. Both in the crop cultivation phase as well as the animal husbandry phase, nitrogen flows are very relevant for a potential release of nitrous oxide. This is especially related to mineral fertilizer inputs in the feed crop cultivation (all crops except soybean) and to the nitrogen excreted by the animals in the husbandry phase.

Comparison between systems

The clear differences between VMA-fiber production and chicken meat production in regards to stratospheric ozone depletion are the high-input cultivation practices for chicken feed, which is not

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needed for the VMA-fiber products due to the nitrogen fixation ability of legumes. Just the cultivation alone, which includes mineral-N fertilizer application, releases more nitrous oxide than all of the VMA-fiber product processes. In addition the nitrogen excreted by the animals as a result of feed nitrogen input and nitrogen requirements is a key parameter for potential nitrous oxide emissions.

Phosphate rock (CRD)

P2F prototypes: VMA-fiber

The cultivation of the legumes for the VMA-fiber products uses the largest amount of phosphate rock due to the application of mineral fertilizer P_2O_5. The cultivation of lupin and lentil requires nearly the same amount of fertilizer application (13 kg P_2O_5/t crop / 12 P_2O_5/t crop), but the lupin-based VMA-fiber products need a considerably higher seed mass input per product than lentil-based VMA-fiber products. Therefore, the cultivation of lupin uses twice as much phosphate rock as the cultivation of lentil for the production of the VMA-fiber product.

Whereas the difference between phosphate rock for amaranth and buckwheat results mainly from different phosphate requirements. The cultivation of amaranth uses more phosphate in the application of mineral fertilizer in comparison to buckwheat cultivation at 35 kg P_2O_5/t crop and 20 kg P_2O_5/t crop, respectively.

Reference product: traditional chicken meat

The phosphorus and land requirements show a strong dependence on the amount of seeds required per functional unit. Thus, the production of high-impact chicken meat requires more chicken feed and therefore more mineral fertilizers than the low-impact chicken meat.

Comparison between systems

Chicken meat production needs a considerably higher seed mass input per product than VMA-fiber products, but the cultivation of feed crops requires less P_2O_5 fertilizer application than the cultivation of P2F crops, except of rapeseed (19.3 kg P_2O_5/kg crop).

Both chicken meat scenarios show higher phosphate rock demand compared with the lentil-based innovative VMA-fiber product due to a more than three times higher seed mass input. In contrast, the low-impact chicken meat production requires only more than 1.5 times as much of seed mass compared to the lupin-based innovative VMA-fiber products. Therefore, this VMA-fiber product show only lower results in phosphate rock compared to the high-impact chicken meat product.

Cumulative Energy Demand (CED): non-renewable

P2F prototypes: VMA-fiber

Non-renewable energy from the production of VMA-fiber products is mostly required by the crop processing for the protein isolate. Furthermore, processing of the lupin protein isolate, as well as the cultivation of these legumes, requires more non-renewable energy than for lentil protein isolate and lentil cultivation. The drivers behind the non-renewable energy demand for cultivation are the production of fertilizers and pesticides as well as diesel demand for field work. Primary energy demand for lupin protein isolation is around 1.75 times as high as for lentil protein isolation. This is related to both processing energy required as well as energy required to produce processing chemicals such as acids and bases etc.

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The result pattern shows the electricity demand of the several process steps. Electricity is used mainly for crop and final product processing. Following isolate processing steps consume the most electric energy: extraction & centrifugation, precipitation & centrifugation and neutralization & drying.

Reference product: traditional chicken meat

Chicken production requires non-renewable cumulative energy across the stages of transportation, slaughterhouse, animal husbandry, crop processing feed, and feed cultivation. For example the production of electrical energy uses non-renewable fossil energy prechains, and this electrical energy consumption is the main contributor to non-renewable CED for the slaughterhouse, animal husbandry, and crop processing feed stages. Within feed cultivation, wheat, soybean and palm fruit require the most non-renewable energy per chicken meat product. The main drivers are pesticide and fertilizer production and agricultural machine operation.

Nitrogen credits associated with the chicken meat reduce the overall non-renewable primary energy demand of the chicken systems. Nitrogen credits result from usage of nitrogen in manure as a replacement for mineral nitrogen fertilizer.

Comparison between systems

Lentil-based VMA-fiber is associated with lower or comparable demand in non-renewable primary energy than traditional chicken meat. On the other hand, lupin-based VMA-fiber is within the range of low-impact and high-impact chicken meat.

Blue Water: process

P2F prototypes: VMA-fiber

The majority of process blue water for the VMA-fiber products is used during the crop processing protein isolation stage as it is an aquaeous extraction. The protein extraction of lupin isolate requires more water using processing stages than the lentil processing. Therefore, three times more process water is needed for the protein extraction of lupin isolate than for lentil isolate. Cultivation related process water is used for production of fertilizers and pesticides. Consequently, the more fertilizers and pesticides are needed for crop cultivation the higher is the process water demand

The lupin-based VMA-fiber products need a considerably higher seed mass input per product than lentil-based VMA-fiber products. Therefore, the cultivation of lupin uses twice as much phosphate rock as the cultivation of lentil for the production of the VMA-fiber product. As field crops are assumed to be non-irrigated in the base LCA model, irrigation water does not show up in the cultivation step.

Reference product: traditional chicken meat

The majority of process blue water for the chicken meat production is used for cultivation, animal husbandry and slaughterhouse. Similar to the cultivation for VMA-fiber products, the process water is required for the pesticide and fertilizer production. As feed crops are assumed to be non-irrigated in the base LCA model, irrigation water does not show up in this system. Husbandry related process water is used as drinking water for the chickens and slaughterhouse related water is used for cleaning and washing.

Comparison between systems

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 635727.

The crop processing of P2F crops needs a lot more process water compared to the feed processing for the chicken meat products. In contrast to the water consumption of lentil isolate processing; the process water consumption for lupin isolate exceeds the water consumed by the phases of chicken production. Therefore, lentil-based VMA-products perform favourable and the lupin-based VMA-products non favourable compared to both chicken meat production scenarios regarding in the category process blue water demand.

Land Use

P2F prototypes: VMA-fiber

More land area is required for the production of lentils than for lupines because lupin produces more yield on one hectare (2.5 t/ha) than lentil (0.8 t/ha). This means that per kilogram of crop, lupines require 4 square meters of land, while lentils require more land (12.5 square meters) per kg of produced crop.

Reference product: traditional chicken meat

Similar to the cultivation for VMA-fiber products, the land area required for the feed crops is a function of the yield. For example, the area required for the production of soybeans is relatively higher than for wheat or maize because wheat or maize produces more yield per hectare (7.9 t/ha / 9.8 t/ha) than soybean (2.82 t/ha).

Comparison between systems

The low-impact and high-impact chicken meat scenarios show lower results for land use compared to the innovative VMA-fiber products. This is due to higher yields per hectare for most of the feed crops than for the P2F crops.

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3.1.2. VMA-spread (sectoral)

The following figures (Figure 3-6 to Figure 3-9) illustrate sectoral LCA results of VMA-spread product group.

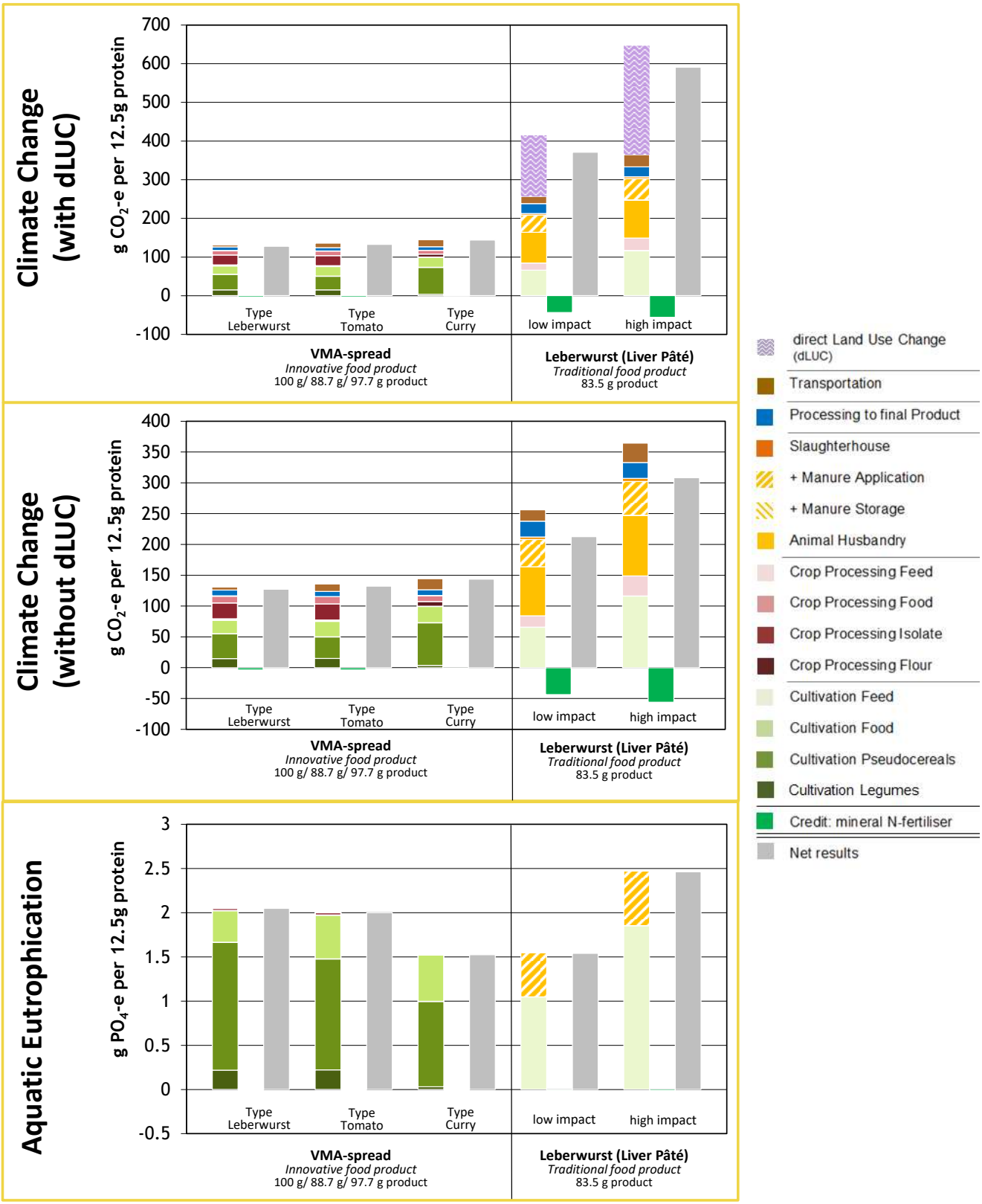

Figure 3-6: sectoral LCA results of spread, indicators: Climate Change (with and without dLUC), and Aquatic Eutrophication (VMA: vegetable meat alternative)

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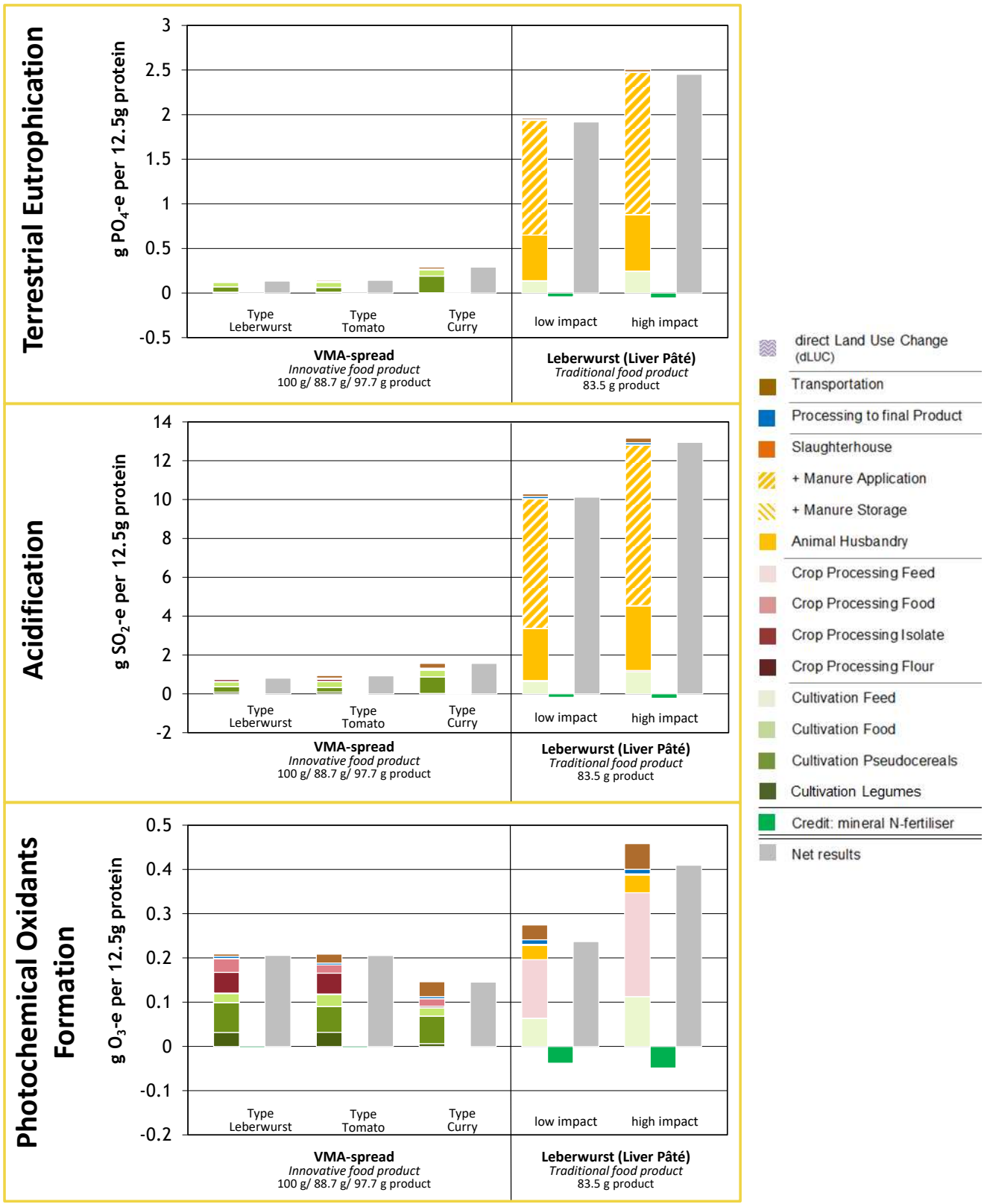

Figure 3-7: sectoral LCA results of spread, indicators: Terrestrial Eutrophication, Acidification, and Photochemical Oxidants Formation (VMA: vegetable meat alternative)

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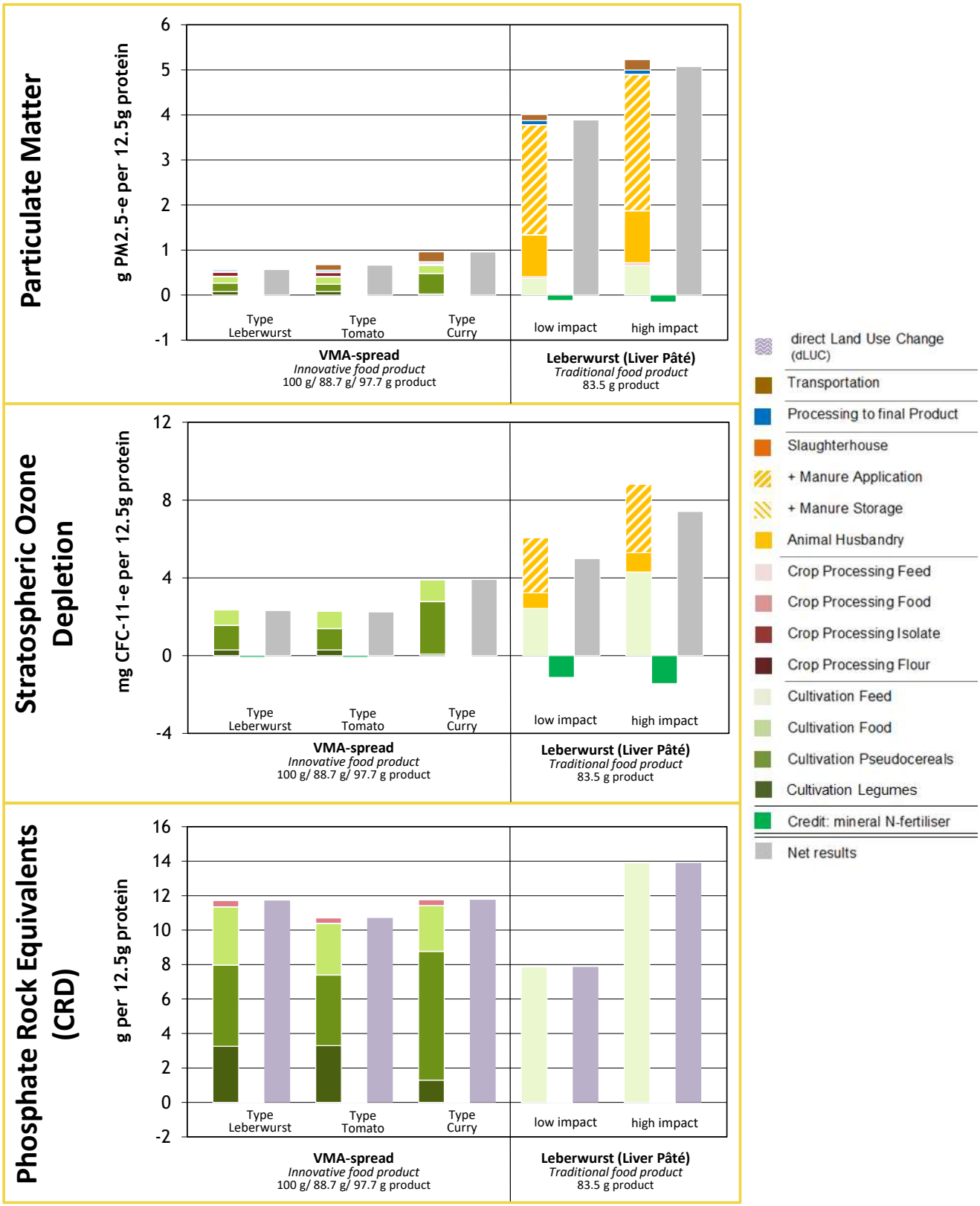

Figure 3-8: sectoral LCA results of spread, indicators: Particulate Matter, Stratospheric Ozone Depletion and Phosphate Rock (CRD) (VMA: vegetable meat alternative, CRD: cumulative resource demand)

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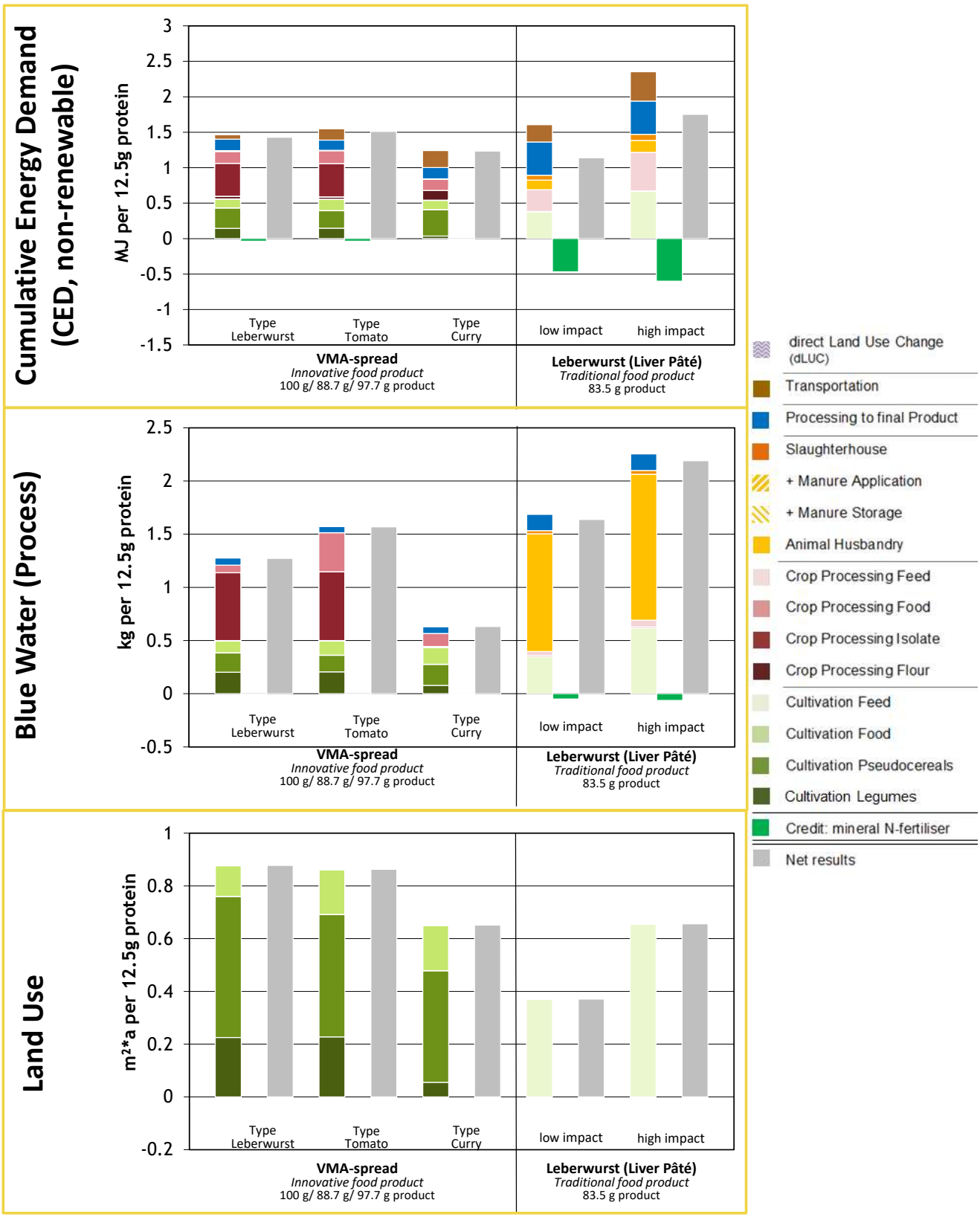

Figure 3-9: sectoral LCA results of spread, indicators: Cumulative Energy Demand (CED, non-renewable), Blue Water (Process), Land Use (VMA: vegetable meat alternative)

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Climate Change (with and without dLUC)

P2F prototypes: VMA-spread

The stage of crop cultivation for the three VMA-spread products generates the highest amount of greenhouse gas emissions. Especially, the pseudocereal cultivation for the VMA-spread type curry which uses quinoa rather than buckwheat, creates higher greenhouse gas emissions compared to the other two types. This results from the higher nitrous oxide emissions during cultivation and the higher demand of fertilizers for quinoa. The latter is a consequence of the following points:

1. The processing of quinoa flour requires about 2 times more seed input per kg flour compared to buckwheat flour. Therefore, more seeds have to be cultivated per kg quinoa flour, compared to buckwheat flour.
2. The cultivation of quinoa seeds needs a higher nitrogen fertilizer input (48 kg/t) than the cultivation of buckwheat seeds (20 kg/t). Therefore more fertilizer has to be produced and more nitrous emissions are released. The consequence is a higher GWP for the production of quinoa seeds than for the production of buckwheat seeds.

The crop processing of the VMA-spread type curry has the lowest impact on climate change compared to the two other types. This is due to the fact that it does not use protein isolates as an ingredient.

Other processes that are associated with greenhouse gas emissions include the final processing and the transportation of crops and components. The latter has especially an important impact, when oversea crops are used for the VMA-spread products. Therefore, the climate change net results differ between the type leberwurst (liver paté) and the two other VMA-spread types.

Reference product: traditional leberwurst (liver paté)

The climate change results (excluding dLUC) of pork based traditional leberwurst show a similar pattern than the traditional chicken meat production. Because spread is a processed food product, the processing of liver and meat to the final product appears as an additional contribution to climate change.

If in addition to that direct land use change impacts[7] are taken into account, related greenhouse gas emissions are with roughly 40 % the main contributors to the overall potential impact on climate change. The land use change impacts are directly related to the feed, in this case due to Brazilian soybean and Malaysian oil palm cultivation.

Comparison between systems

It is clearly visible that the innovative VMA-spread products have a better performance in the category climate change potential. Solely the feed cultivation and processing for the traditional products show nearly the same amount of Greenhouse gas emissions than the net-results of the innovative VMA-spread products.

Aquatic Eutrophication

P2F prototypes: VMA-spread

[7] As stated in section 2.5.1.5 in Deliverable 5.2

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The Aquatic eutrophication potential of the VMA-spread products is primarily caused by the cultivation of pseudocereals and other food ingredients.

Pseudocereal cultivation creates the highest amount of PO_4-equivalent emissions for VMA-spread. Despite the lower pseudocereal (buckwheat) seed mass input for the types Leberwurst and tomato, they show a higher potential impact on aquatic eutrophication than the curry VMA-spread product. The latter uses quinoa as pseudocereal. The root depth of quinoa plants implies a 1.5 times higher nitrogen uptake ability per kg crop compared to buckwheat. This result in higher nitrogen leaching per buckwheat compared to quinoa.

Reference product: traditional Leberwurst

The aquatic eutrophication potential created by the Leberwurst production is largely caused by feed cultivation. Manure application for feed cultivation is the second largest contributor to the aquatic eutrophication potential. This is due to nitrate leaching from the applied manure.

Comparison between systems

Low yields in combination with relative low nitrogen uptake of the P2F crops used for VMA-spread types Leberwurst and Tomato lead to higher results than the low-impact chicken meat product. Only the VMA-spread type curry has a lower aquatic eutrophication potential compared to the traditional Leberwurst product. The reason therefore is the higher yield of pseudocereals that are used for the production of the innovative VMA-spread type curry.

However, high feed mass input as well as the amount of manure production of the high-impact traditional Leberwurst result in a better performance of all three VMA-spread types compared to the high-impact Leberwurst.

Terrestrial Eutrophication, Acidification, and Particulate Matter

P2F prototypes: VMA-spread

The categories of terrestrial eutrophication, acidification, and particulate matter for the production of innovative VMA-spread products show similar result patterns. The impacts are primarily created by the cultivation of legumes, pseudocereals and further food crops. The contributing direct field emissions to the air include ammonia and nitrogen emissions from mineral fertilizer and -in case of legumes-, the release of N_2O from plant residue material.

Especially, the VMA-spread type curry which uses quinoa rather than buckwheat creates higher terrestrial eutrophication, acidification and particulate matter potentials than the other two types. Similar to the climate change results, this effect is caused by different flour processing yields and different nitrogen fertilizer inputs for the quinoa and buckwheat production.

Furthermore, the potential impact on particulate matter formation and acidification of the oversea transportation of crops is clearly visible.

Reference product: traditional Leberwurst

The emissions that contribute to terrestrial eutrophication, acidification, and particulate matter formation in regards to pork Leberwurst production result primarily from the manure application: 67 %, 66 %, and 63 % respectively. Animal husbandry contributes secondary to the three categories. For both phases, the main emission released by manure is ammonia. Furthermore, the impact of the oversea transportation is clearly visible.

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Comparison between systems

The production of pork Leberwurst has a higher potential to cause terrestrial eutrophication, acidification, and particulate matter formation compared to the innovative VMA-spread products. This result is due to direct effects of animal husbandry and subsequent manure application.

Photochemical-Ozone Formation

P2F prototypes: VMA-spread

Similar to the previous categories, the photochemical-ozone formation results of the cultivation and processing of non-leguminous ingredients are more significant than the photochemical-ozone formation results of legume ingredients for the three VMA-spread products.

The non-methane volatile organic emissions are firstly, created by the following combustion processes:

- diesel-driven field machinery for cultivation
- transportation of crops from oversea
- energy generation for chemical prechains and crop processing.

Secondly, the photochemical-ozone formation potential is related to hexane emissions from the following solvent extraction processes:

- extraction of lupine protein isolate used for the VMA-spread types Leberwurst and tomato
- production of canola oil needed for all three innovative products

The type curry is made of the least processed protein ingredients Therefore; this type has the lowest potential to cause photochemical-ozone formation compared to the other two innovative VMA-spread products.

Reference product: traditional Leberwurst

Traditional Leberwurst production has a higher potential to cause photochemical-ozone formation than the innovative counterparts. Most of the emissions contributing to the higher potential are the result of feed crop processing, cultivation and transportation. In contrast to the feed for chicken husbandry, the main feed components for pig husbandry are less processed. Therefore, the potential ozone equivalents from feed processing don't dominate entirely the overall photochemical-ozone formation results.

Comparison between systems

The pork Leberwurst production has a higher potential to cause photochemical-ozone formation compared to the innovative VMA-spread products. This result is due to the feed crop processing and the transports of the feed components to the husbandry.

Stratospheric Ozone Depletion

P2F prototypes: VMA-spread

Stratospheric ozone depletion potential of the VMA-spread products is caused by the cultivation of legumes, pseudocereals and other food ingredients according to their share in the VMA-spread products. For pseudocereals and food ingredients, the contributing gas is nitrous oxide that is

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associated with the use of mineral fertilizers. For legumes, the contributing gas is related to the nitrogen released as nitrous oxide by plant residue material.

Similar to the categories terrestrial eutrophication, acidification and particulate matter, the VMA-spread type curry creates a higher stratospheric ozone depletion potential than the other two spread types. This results again from the higher nitrogen fertilizer input during the cultivation of quinoa seeds and the lower product yield of the flour production.

Reference product: traditional Leberwurst

The phases of the chicken meat production that result in stratospheric ozone depletion include mainly the feed cultivation and manure application. Pig husbandry operation releases only half of the nitrous oxide emissions of the chicken husbandry per kg livestock . Therefore, this life cycle step plays only a minor role for the production of Leberwurst regarding stratospheric ozone depletion.

Comparison between systems

The clear differences between VMA-spread production and pork Leberwurst production in regards to stratospheric ozone depletion are the high-input cultivation practices for pork lever and meat as well as the manure application. Thus, the pork Leberwurst production has a higher potential to cause stratospheric ozone depletion compared to the innovative VMA-spread products.

Phosphate rock (CRD)

P2F prototypes: VMA-spread

The cultivation of legumes, pseudocereals and further food crops for the VMA-spread products uses most phosphate rock due to the application of mineral fertilizer P_2O_5. The differences between phosphate rock for the three spread types result from different phosphate requirements, and especially from different seed inputs. For example the type curry requires twice as much pseudocereal seeds as the two other types.

Furthermore, a relative small amount of phosphate rock is required in the rapeseed processing step due to the use of phosphate acid.

All in all, the tomato VMA-spread product benefits from the higher protein content than the other types and the lower product mass per functional unit as a consequence.

Reference product: traditional Leberwurst

Similar to the chicken meat production, the phosphorus requirements for the Leberwurst production show a strong dependence on the amount of seeds required per functional unit.

Comparison between systems

Only the higher-impact Leberwurst scenario shows higher equivalents for phosphate rock compared to the VMA-spread types. This is due to a higher seed mass input.

In contrast, the low-impact traditional Leberwurst needs more phosphate rock than the VMA-spread products. This is a consequence of the fact that the crops used for these VMA-spread products have higher phosphate requirements than the feed crops.

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Cumulative Energy Demand (CED): non-renewable

P2F prototypes: VMA-spread

The VMA-spread production has a relatively homogenous demand for non-renewable cumulative energy across all production phases. The high demand for non-renewable energy for the lupin isolate processing is clearly visible in the results of the VMA-spread type tomato and Leberwurst.

Similar to the climate change results, the cultivation of pseudocereals for the curry VMA-spread products shows a higher CED than for the two other innovative prototypes. This is not a consequence of the diesel usage for field work, but of the different fertilizer requirements of quinoa and buckwheat. Quinoa cultivation needs more nitrogen and phosphor fertilizer input than buckwheat cultivation. As the crop yield of buckwheat is 2.5 times lower than for quinoa, the about 2.2 times lower yield of quinoa flour during the milling process (for protein-rich flour) is compensated, compared to buckwheat flour. Therefore, the CED of the field machine operation is almost the same for both cultivation systems per VMA-spread product.

It should be noted that lupin isolate processing requires clearly more energy than the other crop processing stages. The type curry doesn't need any isolate processing for the production of the ingredients. Therefore, this type shows the lowest total CED results compared to the two other innovative VMA-spread products.

Reference product: traditional Leberwurst

Pork based Leberwurst production has a relatively homogenous demand for non-renewable cumulative energy during transportation, processing to the final product, slaughtering, pork production (animal husbandry, slaughteering), crop processing, and feed cultivation.

Comparison between systems

Innovative VMA-spread products are within the range of low-impact and high-impact traditional Leberwurst. For a good part this is related to the relatively high demand in process energy for protein isolation. However, the high-impact Leberwurst shows higher CED non-renewable results than the type Leberwurst and type tomato VMA-spread products.

Blue Water: process

P2F prototypes: VMA-spread

Most of the blue water for the VMA-spread product type Leberwurst and tomato is required during protein isolate processing because it is an aqueous extraction. According to the results of the tomato VMA-spread production, water used for tomato receiving and washing at the tomato paste processing plant appears to be the second largest contribution to blue water demand. The reason therefore is the assumption (in the original data source) that that half of the water for washing and receiving of tomatoes doesn't circulate in the system.

As the recipe for the type curry requires the least processed ingredients, the curry VMA-spread product has the best performance regarding the category blue water.

Reference product: traditional Leberwurst

Most of the blue water for the traditional Leberwurst production is used for feed crop cultivation and animal husbandry. Similar to the production of VMA-fiber, the process water associated with

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the cultivation is required for the pesticide and fertilizer production. As feed crops are assumed to be non-irrigated in the base LCA model, irrigation water doesn't show up in this system. Husbandry related process water is used as water for the pigs. In contrast to the chicken meat production, less process water is used in the slaughterhouse for pork meat and pork liver production. This results primarily from a 13 times lower economic value of liver. Secondly, the cleaning and washing water for the pork slaughtering is six times lower than for chicken.

Comparison between systems

Both pork Leberwurst scenarios show higher results for process blue water compared to the VMA-spread products type curry and Leberwurst. Whereas the feed cultivation of the traditional product shows similar results than the crop cultivation of the prototypes, the process water demand exceeds the crop processing results by far.

In contrast, the conservative water use assumption of tomato paste processing leads to approximately the same process water results of low-impact traditional Leberwurst and tomato VMA-spread product.

Land Use

P2F prototypes: VMA-spread

The curry VMA-spread product requires less land than the two other innovative VMA-spread products due to the following reasons.

The crop yield for buckwheat is 2.5 times lower than for quinoa, but the flour processing yield of quinoa flour is about 2.2 times lower than for buckwheat flour. The difference in crop yield between the two pseudo cereals exceeds the difference of the processing yield. Therefore, the land area associated with pseudocereals for the VMA-spread types Leberwurst and tomato is higher than for the type curry.

Furthermore, the type curry doesn't use legume isolates, but legume flower.

Reference product: traditional Leberwurst

Similar to the cultivation for VMA-fiber products, the land area required for the feed crops is a function of the yield and the mass of feed cultivated for pig husbandry. High- and low-impact scenarios are differentiated by allocation factors for liver and pork as well as by the share of liver in the traditional Leberwurst. Accordingly more pigs have to be taken into account for the high-impact scenarios and more feed has to be cultivated. Therefore, the high-impact Leberwurst requires more land than the low-impact traditional spread product.

Comparison between systems

Both traditional Leberwurst scenarios shows lower results for land use compared to the innovative Leberwurst and tomato VMA-spread products. This is due to higher yields per hectare for most of the feed crops than for the P2F crops.

In contrast, the VMA-spread type curry requires less cultivation area than the other two types. Hence, the production of curry VMA-spread product requires about the same area than the production of high-impact traditional Leberwurst. However, the low-impact Leberwurst scenarios show also lower results for land use compared to the innovative curry VMA-spread products

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3.1.3. Vegetable Milk (sectoral)

The following figures (Figure 3-10 to Figure 3-13) illustrate sectoral LCA results of milk.

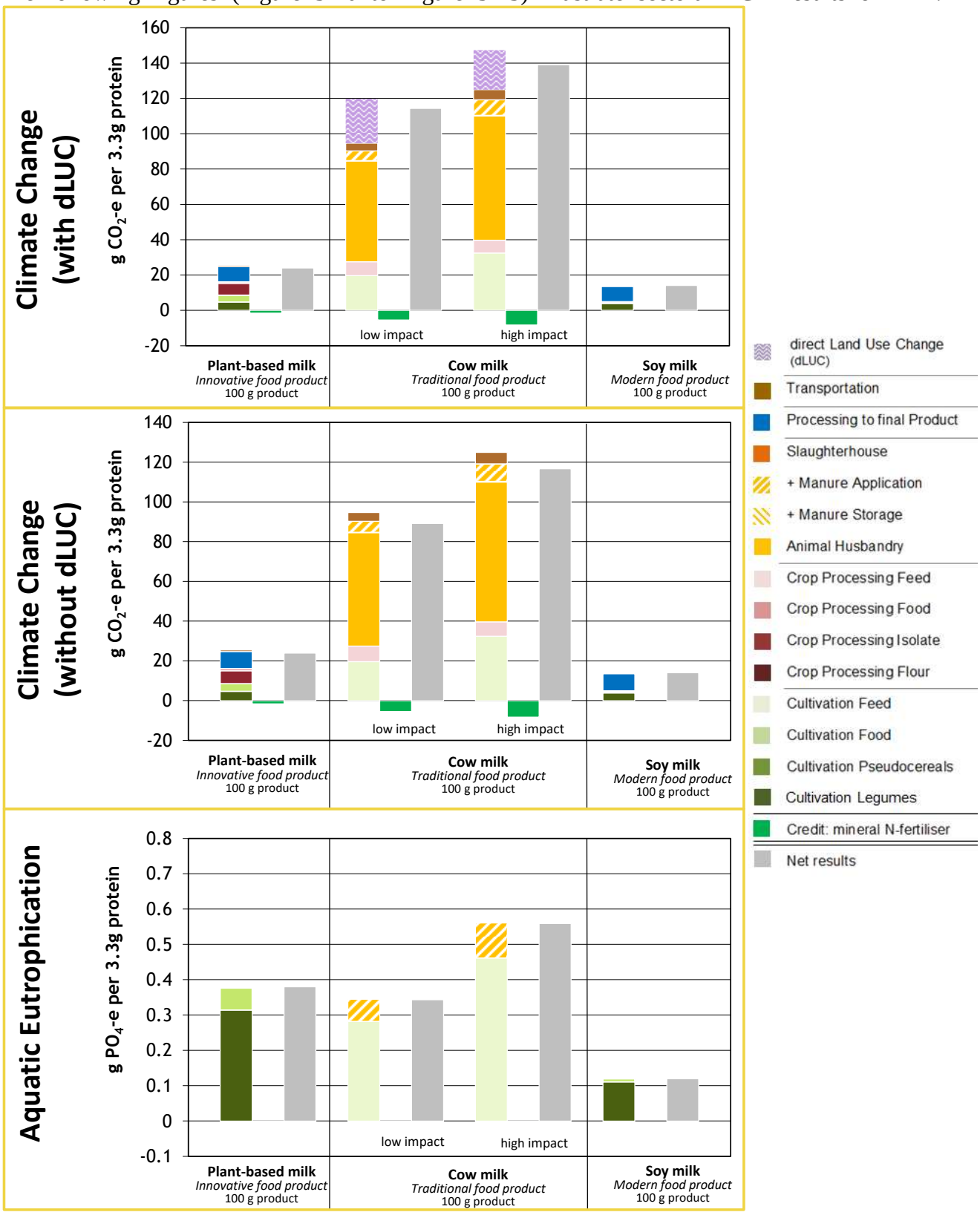

Figure 3-10: sectoral LCA results of milk, indicators: Climate Change (with and without dLUC), Aquatic Eutrophication

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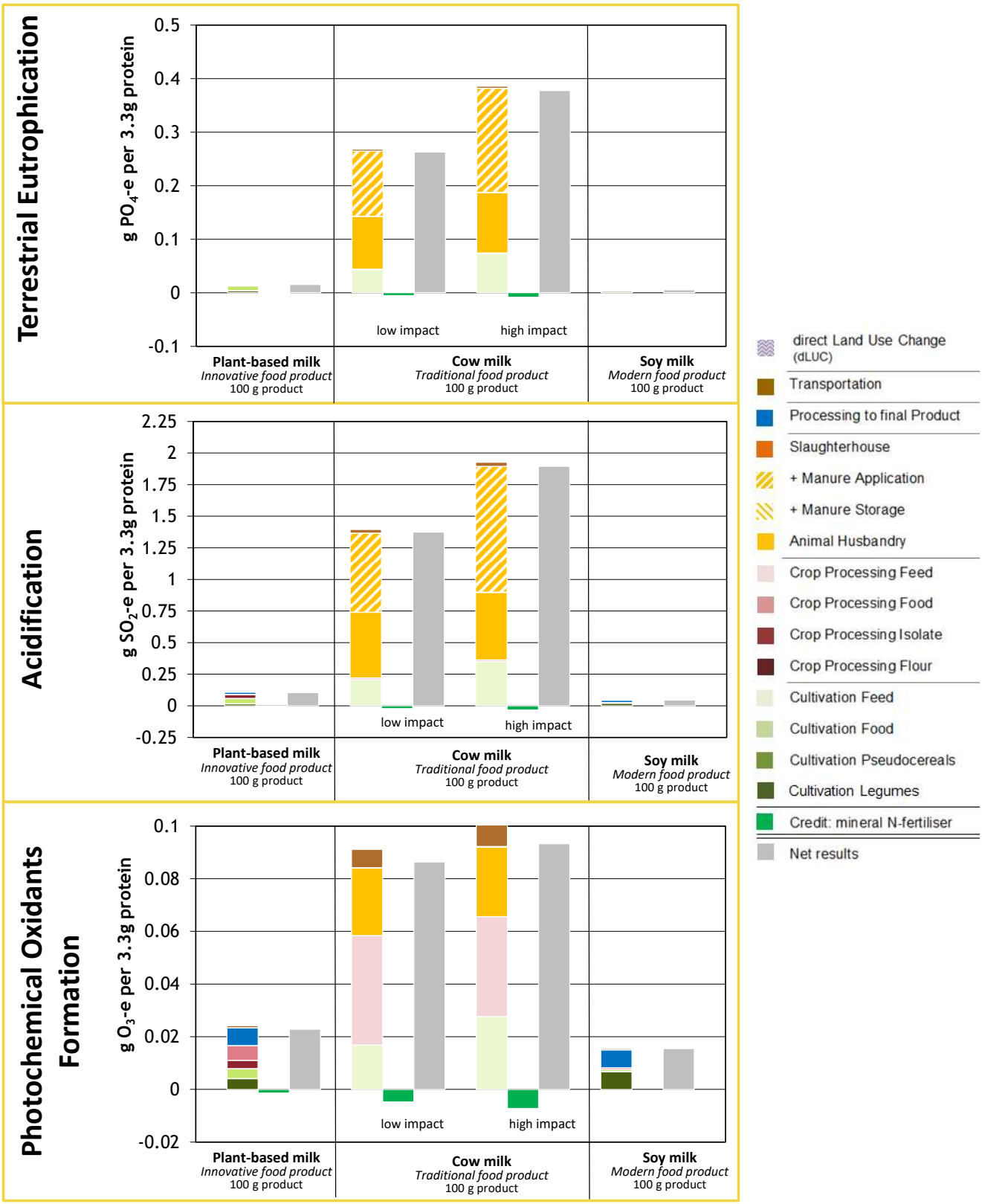

Figure 3-11: sectoral LCA results of milk, indicators: Terrestrial Eutrophication, Acidification, and Photochemical Oxidants Formation

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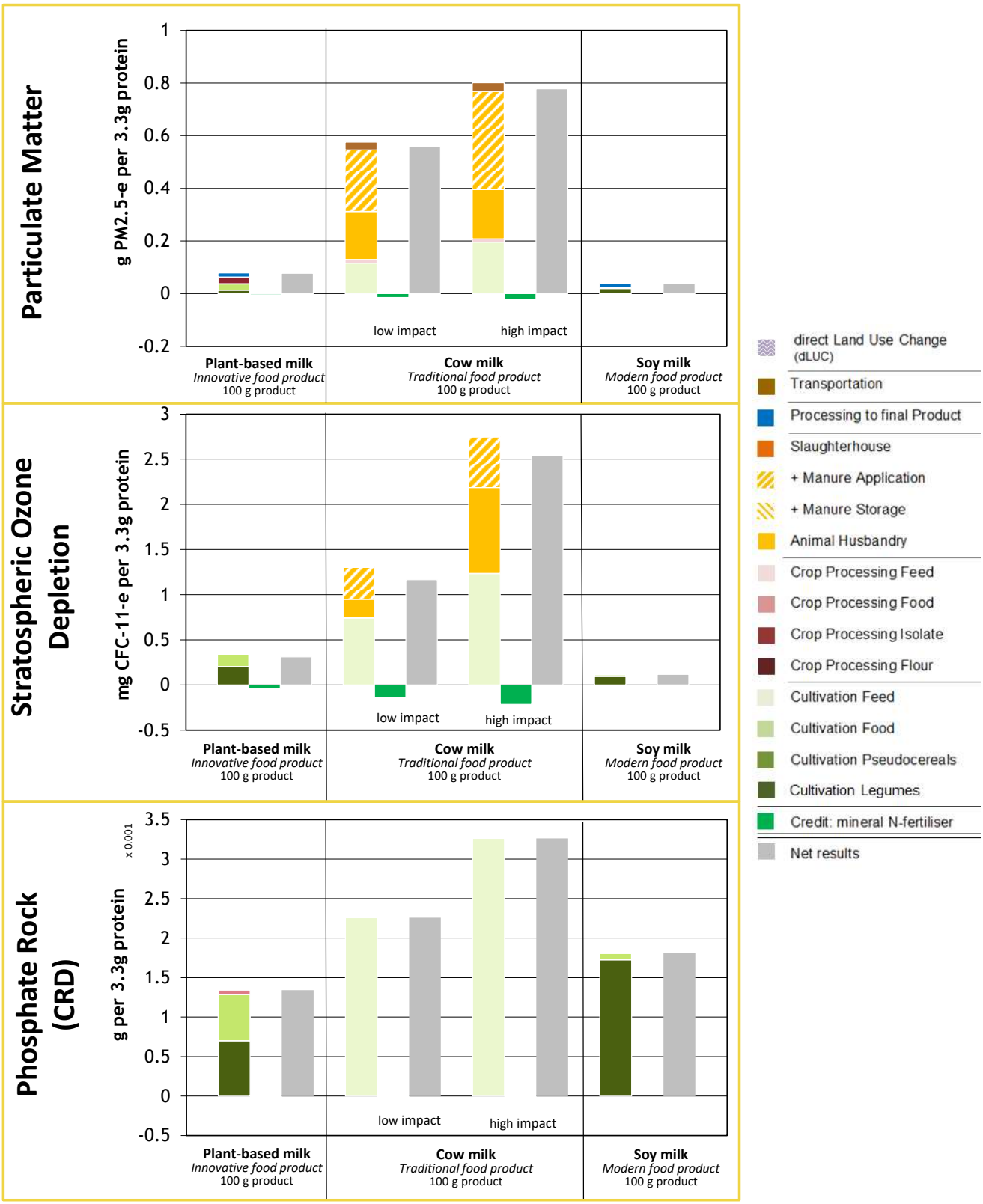

Figure 3-12: sectoral LCA results of milk, indicators: Particulate Matter, Stratospheric Ozone Depletion and Phosphate Rock (CRD) (CRD: cumulative resource demand)

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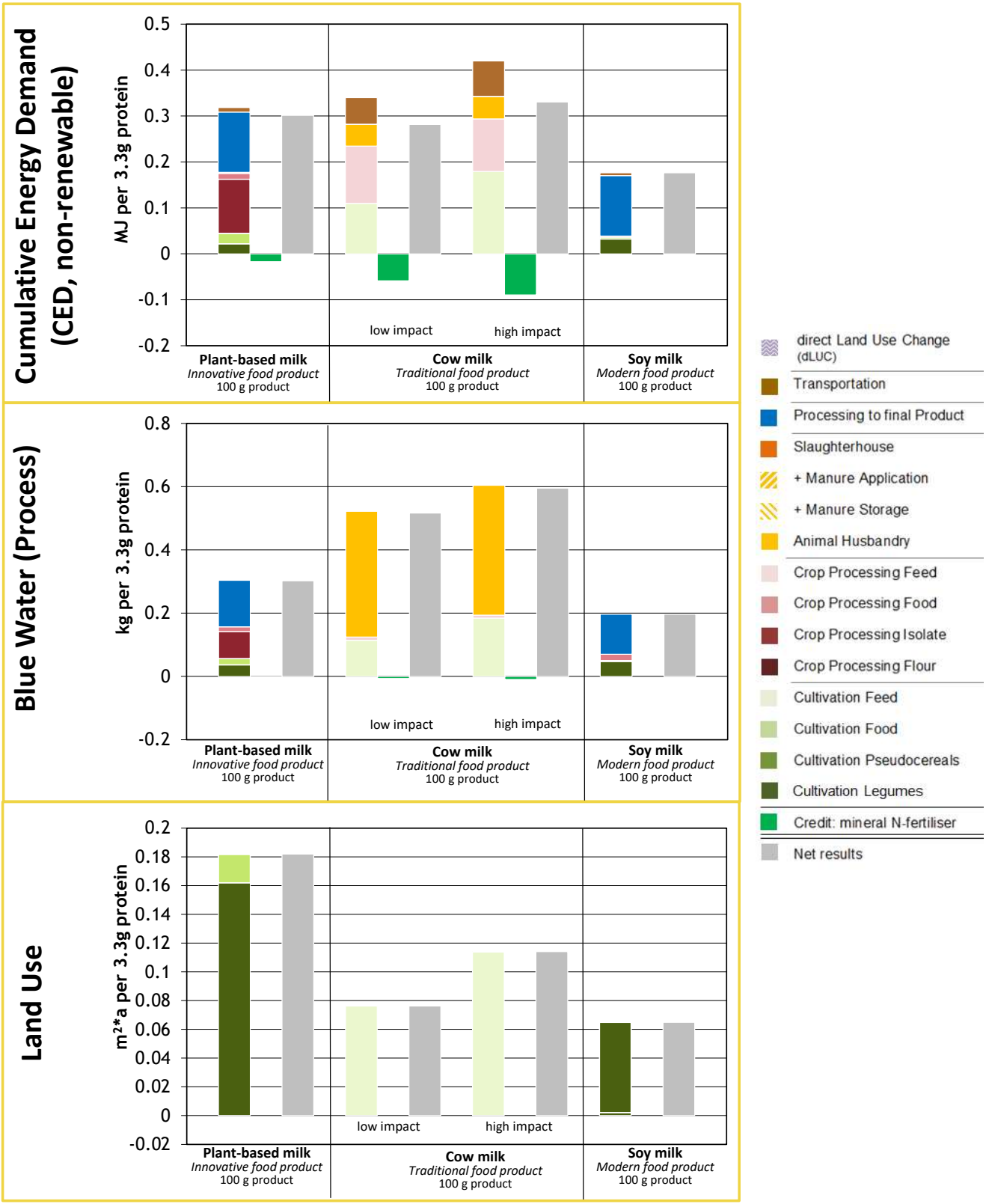

Figure 3-13: sectoral LCA results of milk, indicators: Cumulative Energy Demand (CED, non-renewable), Blue Water (Process), Land Use

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Climate Change (with and without dLUC)

P2F prototype: vegetable milk

The emissions related to climate change potential created by the production of vegetable milk are largely caused by the CO_2 emissions from the stage of processing to the final product, including mixing and homogenizing of the ingredients as well as generation of processing conditions, e.g. provision of a waterbath etc.

In addition to the processing energy-related greenhouse gas emissions, isolation of the protein from the seeds is a relevant contributing life cycle step (again related to processing energy).

The third life cycle step contributing to potential climate change impact is the cultivation of protein-rich legumes as well as cultivation of further ingredients of the vegetable milk (such as sugarcane for sugar production and rapeseed for rapeseed oil). Especially the cultivation of rapeseed in order to produce rapeseed oil is relevant here.

Reference product: traditional cow milk

The majority of greenhouse gas emissions of the cow milk production (both low and high scenarios) come from animal husbandry. Methane is mainly produced by enteric fermentation of cows and it is also released by cow manure. Methane (from enteric fermentation for the predominant part) contributes to the emitted greenhouse gases with 41 %.

Furthermore, the cultivation of feed crops emits the greenhouse gases nitrous oxide, CO_2, and methane. In particular, the production of grass for silage feed, maize for silage feed as well as wheat in the EU for cow feed produces the highest amounts of the following gases: nitrous oxide (related to the use of mineral nitrogen fertilizers on the crop area), carbon dioxide and methane (both related to the use and production of calcium ammonium nitrate and urea as N-fertilizer).

It should also be noted, that more than half of the feed processing burdens come from drying wet sugar beet pulp. This is a consequence of the high water content within the beet pulp and the related relatively high thermal energy demand.

Reference product: modern soy milk

Similar to the innovative milk product, the climate change potential results of modern soy milk come mainly from the generation of electric and thermal energy for the processing of soybeans into soymilk product. The processing in case of soy milk is an integrated processing that includes all process steps required from the whole soybeans, including soaking, grinding of soybeans and dilution of the soybean protein intermediate up to the final soy milk product. As the soybean contains considerable amount of fat, no separate addition of oil (and thus no associated cultivation of other oilseed crops) is required in this case. Sugar-related greenhouse gas emissions are very small (thus not visible in the charts).

Comparison between systems

Overall, both vegetable milk products (modern soy milk as well as innovative P2F vegetable milk) are associated with considerably lower (at least 75% less greenhouse gas emissions for the innovative P2F vegetable milk) greenhouse gas emissions than traditional cow milk products. If additional greenhouse gas emissions associated with land use change for cow milk feed cultivation are taken into account, this reduction is even higher.

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Aquatic Eutrophication

P2F prototypes: vegetable milk

The aquatic eutrophication potential of the innovative vegetable milk is primarily caused by the cultivation of legumes (> 80 % of PO_4-equivalent emissions). This is caused by nitrate leaching from either plant residues or from the soil nitrogen pool. Crop yield is a relevant parameter for nitrate leaching per crop mass.

The other burdens result from the use of mineral fertilizers for cultivation of further ingredients, especially other oil seeds (rape for rapeseed oil).

Reference product: traditional cow milk

PO_4-equivalents which lead to aquatic eutrophication are mostly created by the feed cultivation for traditional milk. Specifically, the (intensive) cultivation of grass and maize for silage feed is associated with nitrate leaching due to the use of mineral fertilizers on the field.

Reference product: modern soy milk

In this case, the main PO_4-equivalent emission causing aquatic eutrophication is also nitrate. It is caused by nitrate leaching from either plant residues or from the soil nitrogen pool. Crop yield is a relevant parameter for nitrate leaching per crop mass.

Comparison between systems

Both vegetable milk products under examination here, soy milk as well as innovative P2F vegetable milk are associated with lower (soy milk) or comparable (innovative vegetable milk) potential aquatic eutrophication than the low-impact cow milk product. A critical parameter in this case is the legume crop yield, as typically European legume crop yields (between 0,8 t/ha and 2,1 t/ha in this case) are lower than those of typical feed crops (e.g. maize, wheat).

Terrestrial Eutrophication, Acidification, and Particulate Matter

P2F prototypes: vegetable milk

The potential impact on terrestrial eutrophication, acidification and particulate matter is primarily created by the cultivation of food crops (rape for rapeseed oil). The contributing emissions to air from cultivation include ammonia and nitrogen emissions from mineral fertilizers as well as emissions from field machinery operations.

Reference product: traditional cow milk

Ammonia emissions that contribute to terrestrial eutrophication, acidification, and particulate matter formation in regards to cow milk production come primarily from manure application. Due to ammonia emissions from manure within the stables, animal husbandry is the second largest emission contributor to the category acidification and eutrophication.

Comparison between systems

Both vegetable milk products under examination here, soy milk as well as innovative P2F vegetable milk are associated with very low potential terrestrial eutrophication, acidification and fine particulate matter impacts. Disappearance of ammonia released from excrements during milk

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cow husbandry if the low-impact cow milk product is replaced by vegetable milk products is the reason for this.

Photochemical Oxidants Formation

P2F prototypes: vegetable milk

The phase of milk processing, crop processing and cultivation are the main production processes of the innovative milk that lead to photochemical oxidants formation potential. Volatile organic compounds as well as formaldehyde are released by several combustion processes, for a good part due to diesel-driven field machinery and processing energy generation.

The photochemical-ozone formation potential associated with crop processing is related to hexane emissions from solvent-based oil extraction processes from the rape seeds.

A closer look at the protein isolate extraction results reveals that about 40 % of the isolate processing emissions come from the production of processing chemicals (e.g. hydrogen chloride and sodium hydroxide) and about 60 % from the generation of energy (electricity and heat). Here again, fuel combustion processes are associated with non-methane volatile organic compound emissions.

Reference product: traditional cow milk

Most of the emissions contributing to the oxidants-formation potential originate from cow husbandry, feed crop processing, cultivation and transportation. Therefore, the potential ozone equivalents from husbandry show a significant contribution to the overall photochemical-ozone formation results.

Reference product: modern soy milk

Similar to the vegetable innovative milk, the phase of final product processing releases the highest share of emissions during the production of modern soymilk. The responsible emissions are created by combustion processes for electricity and heat generation. Further contributions to the photochemical oxidants formation potential for the soy milk system is associated with soy cultivation due to diesel fuel demand for machinery as well as the demand in phosphorus fertilizer.

Comparison between systems

If vegetable milk products replace cow milk, reductions in photochemical oxidants formation potentials are observed. For a good part, this is related to overall reduced machinery use and fertilizer demand of soybean and P2F crop cultivation versus cow feed crop cultivation. Considerable savings in hexane emissions are also observed, due to reduced demand in solvent-based oil extraction in case of vegetable milk systems. Accordingly, also reductions in methane emissions associated with the cow husbandry are one more reason for reduced phtochemical oxidants formation potentials when replacing cow milk by vegetable milk products.

Stratospheric Ozone Depletion

P2F prototypes: vegetable milk

The Stratospheric ozone depletion potential of the innovative vegetable milk is caused by the cultivation of legumes and other food ingredients. For legumes, the contribution is related to the

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nitrogen released as nitrous oxide by plant residue material. For food ingredients, the emitted nitrous oxide is associated with the use of mineral nitrogen fertilizers in the cultivation phase.

Reference product: traditional cow milk

Feed crop cultivation creates the highest contribution to ODP for the production of cow milk. During feed crop cultivation, nitrous oxide, the main-contributing emission, is released from the individual feed crop cultivation practices at varying amounts (in case of crops that require nitrogen fertilizer, it is related to nitrogen fertilizer input for the predominant part). The release of nitrous oxide is highest from the production of silograss and rapeseed. This is a result of the combination of the amount of feed components required per unit of cow milk, as well as cultivation characteristics such as nitrogen fertilizer input required per unit feed crop output.

Reference product: modern soy milk

Similar to the traditional milk production, soymilk production creates nitrous oxide emissions which lead to ODP via the cultivation of the food crop, soybean. However the magnitude is considerably lower, as soybean is a legume and thus nitrous oxide emissions are related to nitrogen released from plant residues and/or soil nitrogen pool.

Comparison between systems

Production of vegetable milk is associated with at least 70% less emissions contributing to stratospheric ozone depletion if compared to traditional cow milk. Achievable reductions may be even higher depending on cow feed mixes assumed / feed conversion ratios for milk cows (see variant cow milk high impact).

Phosphate rock (CRD)

P2F prototypes: vegetable milk

The cultivation of the legumes and further food ingredient crops for the innovative vegetable milk requires phosphate rock due to the application of P_2O_5 fertilizer.

The production of innovative vegetable milk needs twice as much legume seeds as other food ingredient crop seeds. However, the cultivation of food crops uses more phosphate per kg crop in the application of mineral fertilizer in comparison to legume cultivation. Therefore, both crop cultivation groups contribute nearly equal to phosphate rock.

Furthermore, a relatively small amount of phosphate rock is required in the further food ingredient processing step due to the use of phosphoric acid as part of the refining of rapeseed oil.

Reference product: traditional cow milk

The demand of phosphate rock during the production of traditional milk is restricted to feed cultivation due to the application of the mineral fertilizer P_2O_5. The amounts of phosphate rock are higher in case of high impact milk, as they are directly related to the feed crop amounts required. In this case, the high impact milk corresponds to a higher demand of silograss and silomaize.

Reference product: modern soy milk

For the production of soymilk, phosphate rock is required for the production of P_2O_5fertilizer for cultivation of soybeans.

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Comparison between systems

Production of vegetable milks, such as P2F innovative vegetable milk as well as soy milk, is associated with a reduced demand of phosphate rock when compared to traditional cow milk. For example, more than 40% reduction in phosphate rock demand is achieved by replacement of low-impact cow milk by innovative P2F crop vegetable milk.

Cumulative Energy Demand (CED): non-renewable

P2F prototypes: vegetable milk

Processing to the final product is the largest contribution to the non-renewable cumulative energy demand. This is related for a good part to the demand of fossil fuels for electricity generation (to be supplied to the final product processing). Those fossil fuels are lignite, natural gas, hard coal and crude oil. The protein isolation from seeds requires the second highest energy demand in total. This is due to a relatively high energy demand for the drying process after aqueaous isolate extraction. In particular, several processing steps of the isoelectric processing, such as extraction, centrifugation, precipitation, neutralisation and drying are causing a clearly visible energy demand.

Reference product: traditional cow milk

Highest contributions to the demand of non-renewable energy are related to cow feed crop cultivation as well as feed crop processing activities. Feed crop processing non-renewable energy is related to the drying of sugarbeet pulp to be used as feed mix component and extraction of palm oil out of palm fruit bunches for the most part. Non-renewable energy in feed crops is related to grass for silage, rapeseed, maize for silage for a good part and is associated with respective machinery field work as well as fertilizer production necessary for cultivation purposes.

Reference product: modern soy milk

Similar to the vegetable innovative milk, the life cycle step of processing soy beans to the soy milk product requires the highest non-renewable energy demand. . In contrast to the vegetable innovative milk, the ingredient processing doesn't show visible contributions to this indicator. This is related to the fact that soymilk production as examined here takes place as an rather integrated process, starting from whole soybeans (including hulls), through soaking and grinding process steps, up to the soymilk product and also with valuable by-products such as okara.

Comparison between systems

Overall, non-renewable energy demand for innovative vegetable milk is in a comparable range as is traditional cow milk. Soy milk non-renewable energy demand is lower, mostly due to the highly integrated nature of the soymilk production process, where milk is produced from whole (not de-hulled) beans through a soaking and grinding process, and the use of the fat content of the bean itself, thus saving the addition of any other vegetable oil. Process energy demand of the protein isolation process chain is thus of a similar magnitude than the rather integrated soymilk production process.

Blue Water: process

P2F prototypes: vegetable milk

Regarding process water, the processing steps (milk processing and protein isolate processing) require more than 75 % of the process water. The milk production contribution corresponds to the

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water required to form the water content of the vegetable milk product. Protein isolation from the seeds is an aqueaous process which is the reason for the visible process water demand.

Reference product: traditional cow milk

The most process water is required for animal husbandry and feed crop cultivation. In case of feed crop cultivation, the process water is required for the pesticide and fertilizer production. As feed crops are considered to be non-irrigated in the base LCA model, irrigation water does not show up in this system. Husbandry related process water is used as drinking water for the cows.

Reference product: modern soy milk

The final product processing makes up the biggest part of the water demand. The water requirement is related to the soaking of soybeans as part of the soymilk production process well as to the water content of the soymilk product. The process water associated with soybean cultivation is required for the pesticide and fertilizer production.

Comparison between systems

Overall both vegetable milk products have lower process water requirements than traditional cow milk due to the high drinking water demand of milk cows. Thus reductions in overall process water demand is to be expected if cow milk is replaced by innovative P2F vegetable milk.

Land use

P2F prototypes: vegetable milk

More land area is required for the production of legumes for innovative vegetable milk than for further food ingredient crops (rapeseed for oil as ingredient), as the legumes are the main crop input on a mass basis. This effect is then combined with relatively low yields of P2F legume crops (compared to e.g. oilseed yields etc.).

Reference products: traditional cow milk and modern soy milk

Land use for cow milk is related to the land area required for feed crop cultivation. Thus the specific land use for cow milk has a strong relationship to assumed feed mixes (and thus also existing variants in milk cow husbandry with effects on feed mixes). Highest shares in land use for cow milk are associated with soybean and rape cultivation as feed crops that are part of the concentrate feed. Land use associated with more extensive roughage feed production would be even higher.

Comparison between systems

With the typical legume crop yields assumed for vegetable innovative milk products in the current study, the land requirements of innovative vegetable milk are higher than for cow milk under intensive roughage feed conditions. On the other hand, soy milk is an interesting alternative as related land use is in fact lower than cow milk low reference. This also means that if typical legume crop yields for innovative vegetable milk may be increased in the future, related land use requirements would be reduced accordingly.

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3.1.4. Vegetable Burger (sectoral)

The following figures (Figure 3-14 to Figure 3-17) illustrate sectoral LCA results of vegetable and beef burgers.

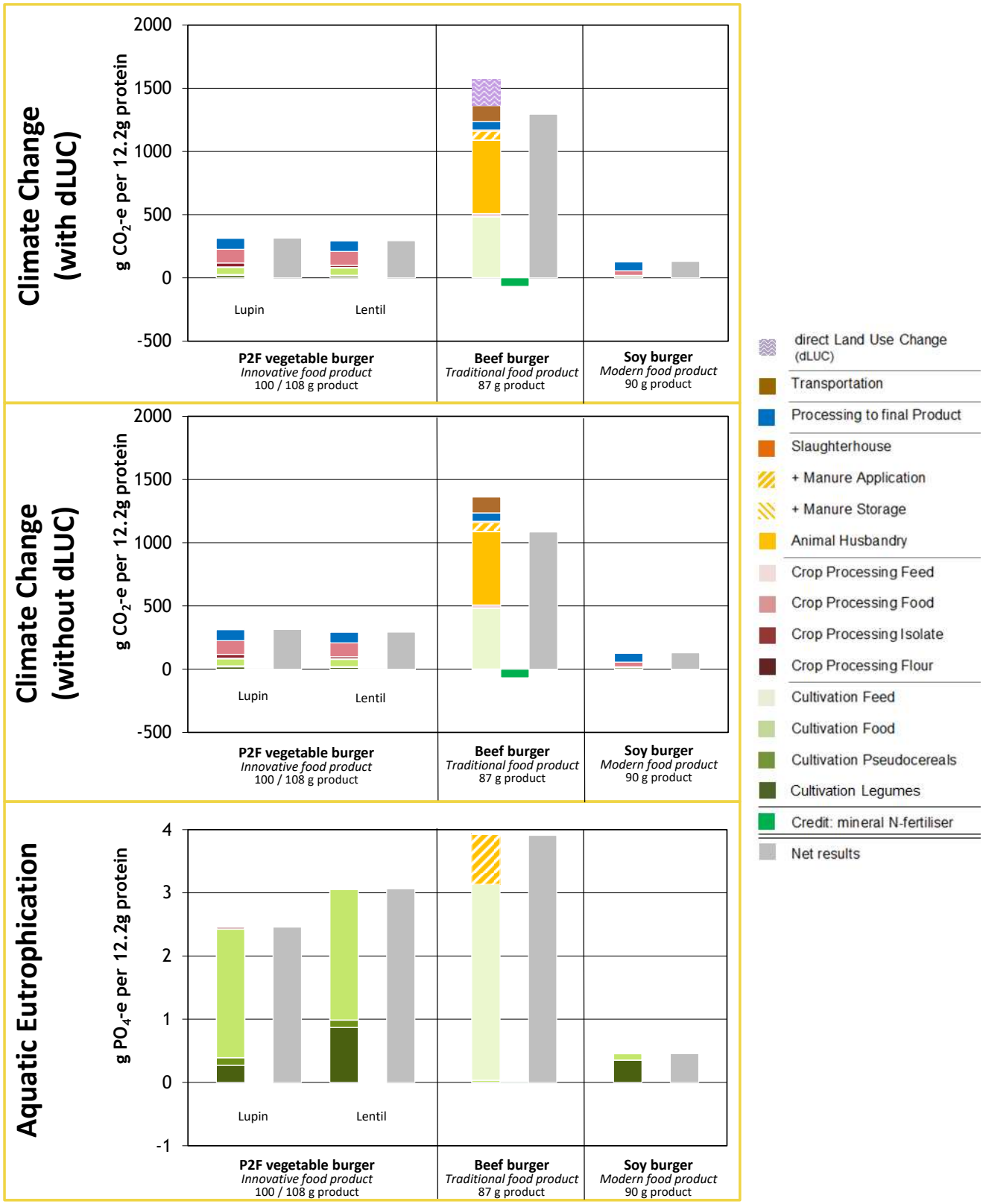

Figure 3-14: sectoral results of vegetable and beef burger, indicators: Climate Change (with and without dLUC), and Aquatic Eutrophication

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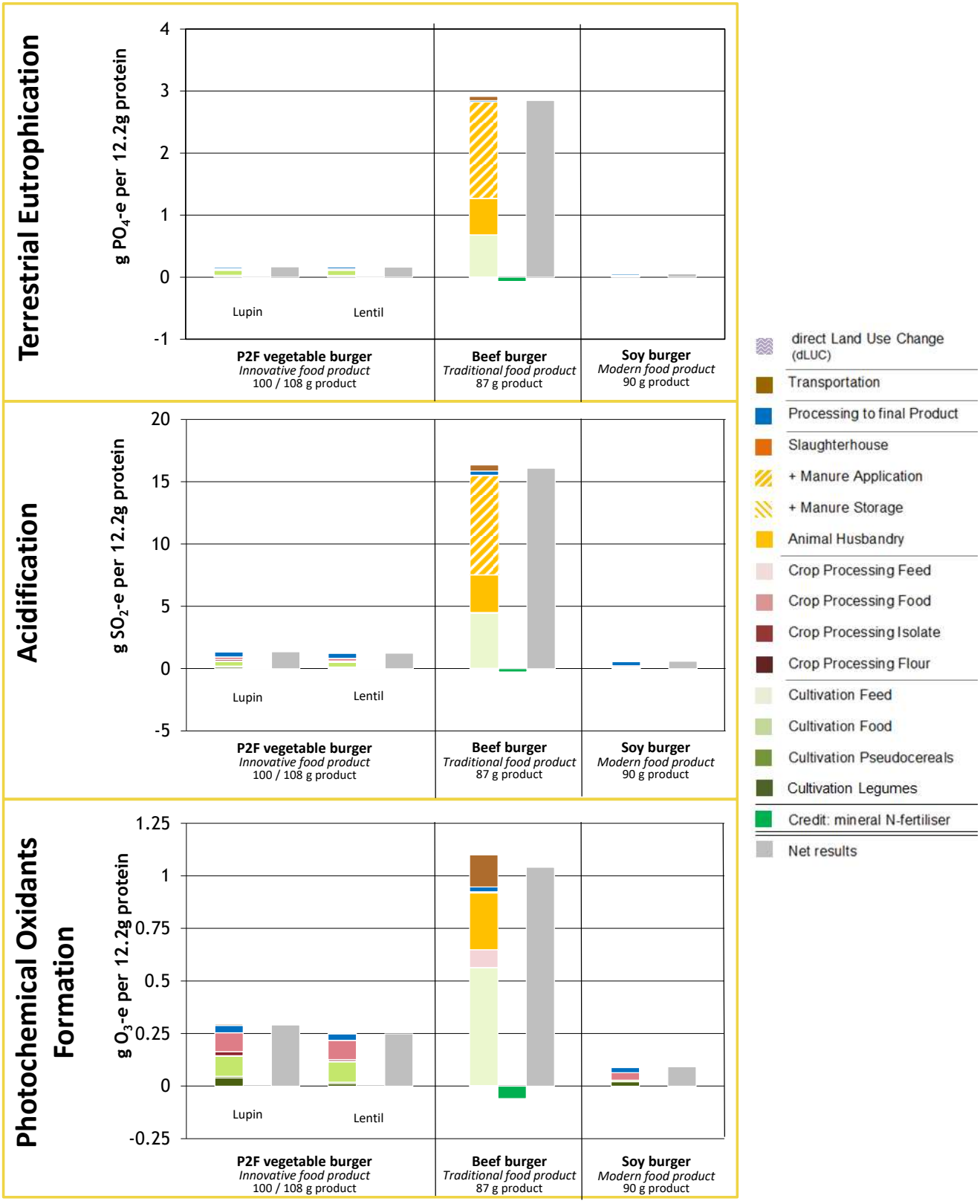

Figure 3-15: sectoral results of vegetable and beef burger, indicators: Terrestrial Eutrophication, Acidification, and Photochemical Oxidants Formation

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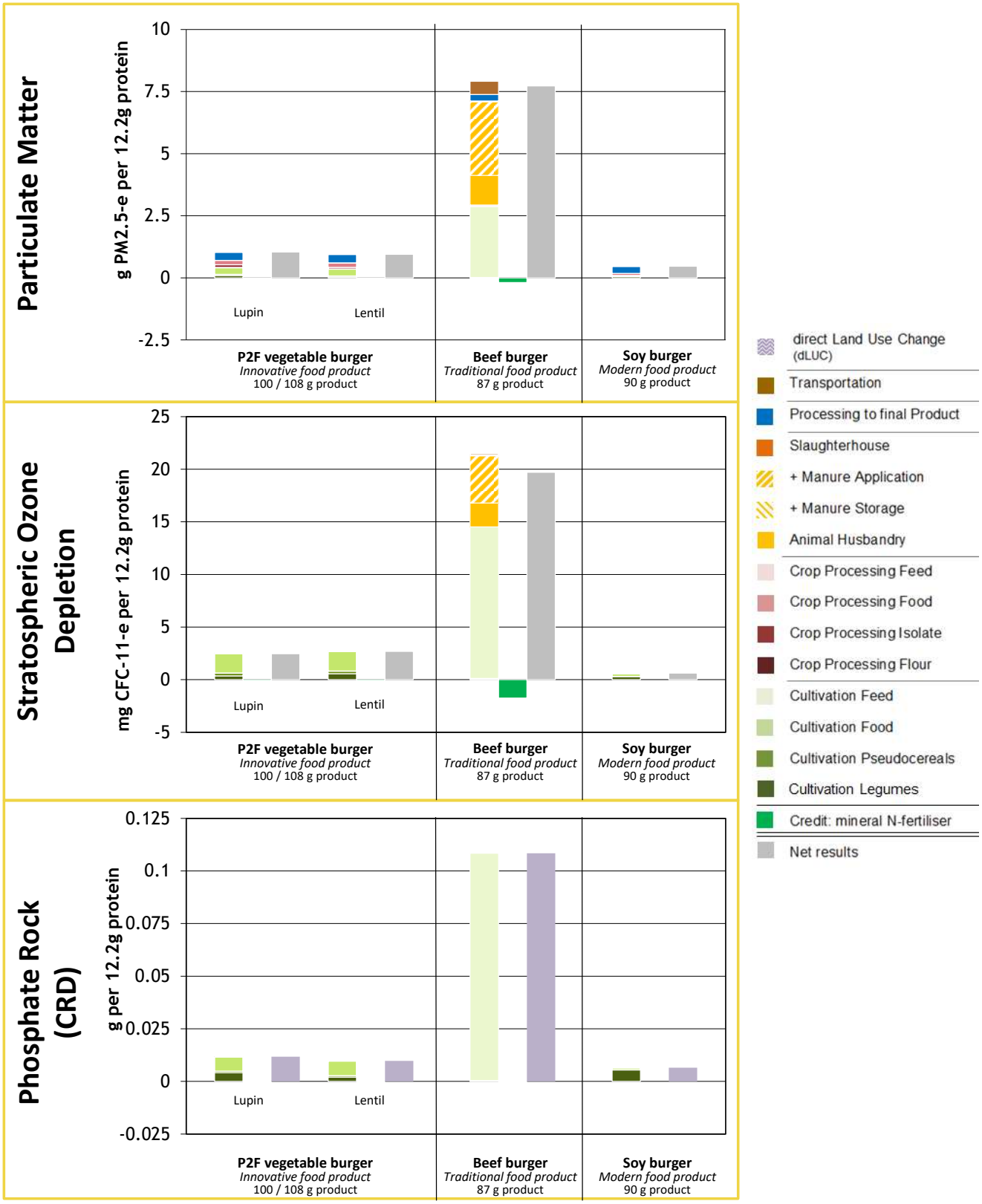

Figure 3-16: sectoral results of vegetable and beef burger, indicators: Particulate Matter, Stratospheric Ozone Depletion, and Phosphate Rock (CRD) (CRD: cumulative resource demand)

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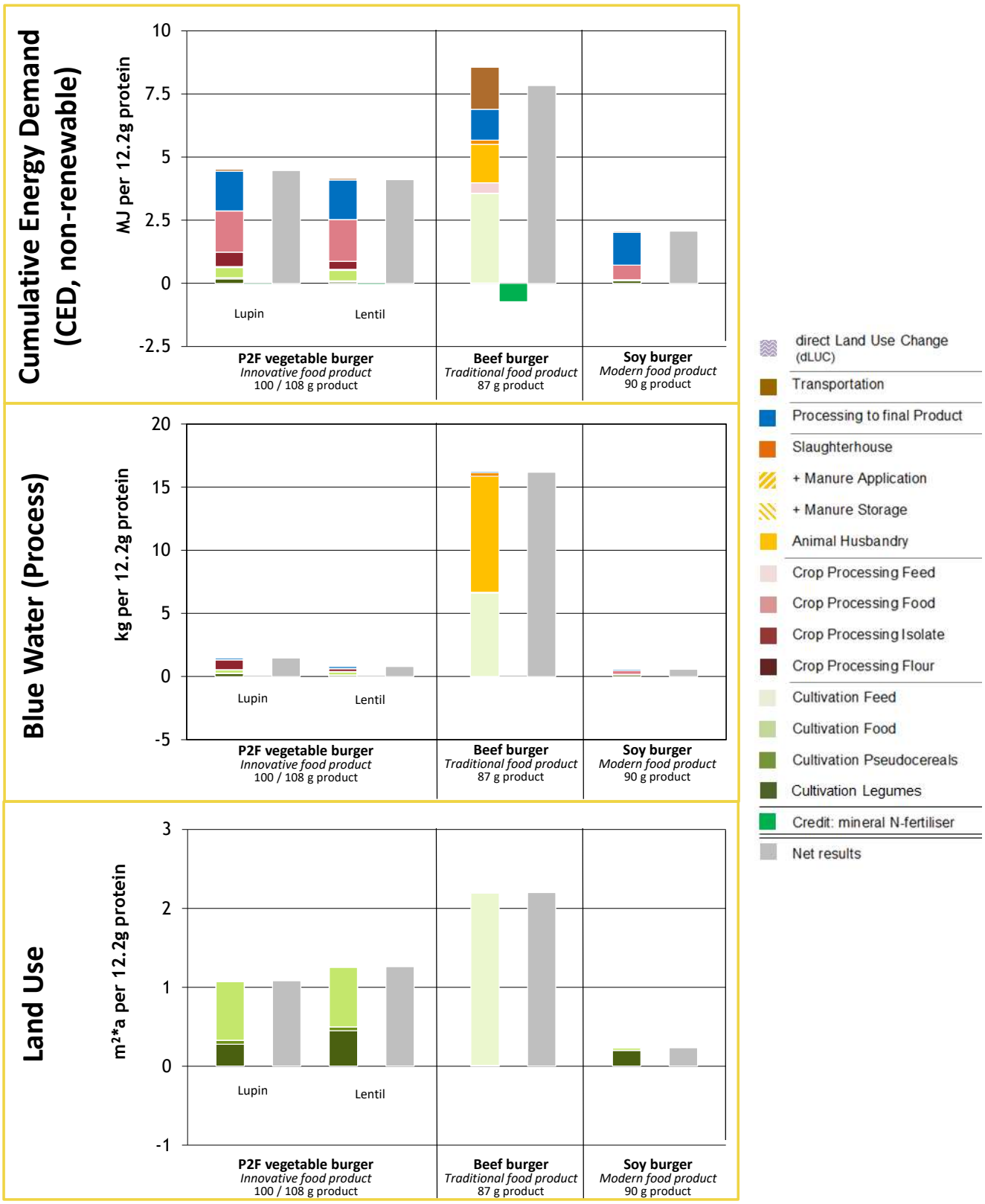

Figure 3-17: sectoral results of vegetable and beef burger, indicators: Cumulative Energy Demand (CED, non-renewable), Blue Water (Process), Land Use

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Climate Change (with and without dLUC)

Beef burger climate change-relevant emissions are dominated by methane emissions (due to enteric fermentation) from the cows in the animal husbandry phase. However, the emissions created from the cultivation of feed, the second-highest contributing production stage, are nitrous oxide and carbon dioxide: nitrous oxide is created in the largest amounts from the use of mineral nitrogen fertilizer in the (intensive) cultivation of grass for silage feed, and carbon dioxide is created mostly from the production of that mineral nitrogen fertilizer.

If direct land use change effects are taken into account, around 1/6 of total greenhouse gas emissions comes additionally on top.

Although small in comparison to beef production, the vegetable burgers still contribute to climate change potential, particularly through the stage of processing the food ingredients to the burger product, as well as ingredient processing (e.g. milling of oat to oat flakes in case of lentil and lupin burgers). In this processing to burger product stage, methane and carbon dioxide emissions are once again the main contributing gasses and they are produced from the generation of process energy to conduct the final processing steps.

The production of the beef burger creates significantly higher climate change potential than the production of the vegetable burgers. For example, the replacement of a beef burger by an innovative lupin-based P2F vegetable burger indicates greenhouse gas emission reduction of at least 70% (without consideration of direct land use change effects), and even more if avoided direct land use change is taken into account.

The use of animals for the beef burger is the differentiating factor between climate change potential of a vegetable burgers versus a beef burger: the methane released by the beef cows during their animal husbandry phase and the use and production of mineral fertilizer on their feeds create the emissions which do not exist in the production of the vegetable burgers. However on the other hand, credits are allocated to beef burger production due to the savings in mineral N-fertilizer through the application of nitrogen containing manure on the field and the production of nitrogen-fixing legumes for cow feed.

Soy burger production based on tofu and okara as ingredients is a quite integrated soybean processing, and as the further product okara is also used in the soy burger the soybeans required as input for those ingredients is relatively low.

Aquatic Eutrophication

Aquatic eutrophication potential created by vegetable burger production is caused by the nitrate emissions from cultivation of other food ingredients for a good part. Majority of those nitrate emissions is related to oat cultivation.

Aquatic eutrophication potential associated with the beef burger is predominantly caused by nitrate leaching in the cultivation of beef feed crops, especially wheat cultivation and (intensive) cultivation of grass for silage feed.

Aquatic eutrophication associated with the soy burger originates from nitrate leaching by nitrogen released by plant residues and / or the soil nitrogen pool.

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P2F vegetable burger production is associated with lower aquatic eutrophication potential than traditional beef burger production, despite relatively high contributions of oat cultivation to this indicator. Soy burger is associated with even lower aquatic eutrophication potential. The latter is due to the highly integrated tofu production from soybeans and the use of the further product (okara) directly from the tofu processing which leads to a comparably low input of soybeans if compared with the various legume, cereal and vegetable ingredients of the innovative P2F vegetable burger.

Terrestrial Eutrophication, Acidification, and Particulate Matter

Comparably quite low emissions related to terrestrial eutrophication are created from the production of the vegetable burgers. The only life cycle step with visible emissions contributing to this indicator is the cultivation of other food ingredient crops for innovative P2F burgers

Acidifying gases are also created in the phase of food crop processing. Oat processing into oat flakes, and to a smaller extent rapeseed milling, tofu processing, and okara processing require process energy and therefore produce acidifying gases associated with electric energy generation.

Processing the vegetable burger into the final product, oat processing into oat flakes as well as cultivation of oats also creates the most emissions related to particulate matter formation. Nitrous dioxide and sulfur dioxide are emitted in approximately equal amounts and are created from the generation of electric energy needed.

In case of the beef burger, life cycle steps with relevant contributions to the terrestrial eutrophication, acidification and fine particulate matter potentials are the cultivation of cow feed crops, ammonia emissions released from excrements in the cow stables as well as ammonia emissions released during manure storage.

Reduction potential associated with a replacement of traditional beef burgers by innovative P2F burgers is very high with regard to nitrous oxides and sulfur dioxide emissions that are the predominant emissions contributing to terrestrial eutrophication, acidification and fine particulate matter.

Ozone Depletion Potential

P2F vegetable burgers show a predominant contribution from oat cultivation phase: More than 85% of the ozone depletion potential is associated with N2O from oat cultivation. On the other hand, legume ingredients are hardly visible, neither for P2F vegetable burgers nor for modern soy burger.

In case of beef again the feed crop cultivation life cycle step is very relevant due to N2O emissions release associated with nitrogen fertilizer application.

Both innovative P2F burger as well as modern soy burger show very low indicator values and thus show relevant reduction potentials for this indicator if a traditional beef burger is replaced.

Photochemical-Ozone Formation

MIR-relevant emissions are created during the food crop processing stage of the vegetable burger production, especially the milling of oats into oat flakes. In particular, the milling of rapeseed into rapeseed oil creates hexane emissions due to the solvent-based oil extraction process, which are the most numerous O3-equivalent emissions. Relevant contributions for the beef burgers are

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associated with the cultivation of feed crops, animal husbandry as well as transport operations. The latter are visible due to fuel combustion processes.

Phosphate rock (CRD)

Phosphorous is used in the largest amounts as part of the cultivation of other food crops due to the demand in P2O5 fertiliser, mostly oat, for the vegetable burger product. Also soy cultivation requires P2O5 fertilizer. Feed crops for beef husbandry show a comparably high P2O5 fertilizer demand. Phosphorus demand of all vegetable burgers is a lot lower than for beef burgers, thus considerable phosphate rock demand reductions are expected when replacing beef burgers by vegetable burgers. For example if an innovative P2F burger based on lentil isolate replaces a traditional beef burger, almost a 90% reduction is expected with regard to phosphate rock demand.

Cumulative Energy Demand (non-renewable)

Vegetable burgers

Non-renewable CED is associated with the stages of processing to the final product and crop food processing into ingredients for the vegetable burger. Primary fossil energy is required to produce the electrical energy used for vegetable burger processing. This fossil energy is just slightly less than the energy required for processing the food crop: in this phase, the non-renewable CED is used for processing the crops soy and rapeseed into their secondary products of tofu and rapeseed oil.

Beef burger

The phases of feed cultivation, animal husbandry, and transportation are associated with the most non-renewable CED of all beef burger production stages. Feed cultivation is associated with the most non-renewable CED, particularly in the production of grass for silage feed and wheat. As the largest consumer of fossil energy within the feed crops, intensive cultivation of grass for silage feed mostly uses the fossil energy to produce mineral fertilizer (77 % of silograss non-renewable CED) and as diesel for agricultural machinery (18 % of silograss non-renewable CED). The non-renewable share of the electricity mix used to measure energy consumption in the animal husbandry phase is responsible for the non-renewable CED use in this phase. Transportation non-renewable CED is attributed to the diesel fuel used in transportation machinery.

Comparison between systems

Beef burger production requires more CED non-renewable than the vegetable burgers. The main differences between the two burger types are seen in the non-renewable CED required by beef in order to cultivate feed crops such as grass for silage feed and wheat, which use energy-demanding mineral fertilizers and agricultural machinery, and the higher transportation required for beef than for the vegetable burger, resulting in higher fossil energy usage.

Blue Water: process

The amounts of blue water needed for the vegetable burger are used during the phases of protein isolation as it is an aqueous process. Within the beef burger system, process water is required for the production of fertilizers required for feed crop cultivation as well as in the husbandry phase as drinking water for the cows.

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Overall, all vegetable burgers indicate considerable savings in blue process water when replacing a traditional beef burger.

Land use

More land area is required for the production of oat than for lupin or lentil for the innovative P2F vegetable burger, as oat is a very relevant crop input on a mass basis.

Land use for beef system is related to the land area required for feed crop cultivation, for a large part related to the grass production for silage feed.

All vegetable burgers indicate reduced land use if compared with traditional beef burgers. Around 50% reduced land use is found for innovative lentil-based P2F burger relative to a traditional beef burger.

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3.2. Condensed results over all indicators (FU = protein)

In this section, LCA results are shown in a condensed format for comparative purposes. A chart example is displayed in **Figure 3-18**. For this purpose, the highest net result of the respective indicator is set to 100%. All other results of this indicator (associated with other examined food products) are then expressed as a percentage relative to the 100% highest result. In the format example given below, chicken meat high has the highest net indicator result. VMA-fiber food products are around 30% to 50% of the highest value. This means e.g. that if such a high-impact chicken meat is replaced by a VMA-fiber product, related greenhouse gas emissions are reduced down to 50%/30%, which corresponds to a 50% to 70% emission reduction.

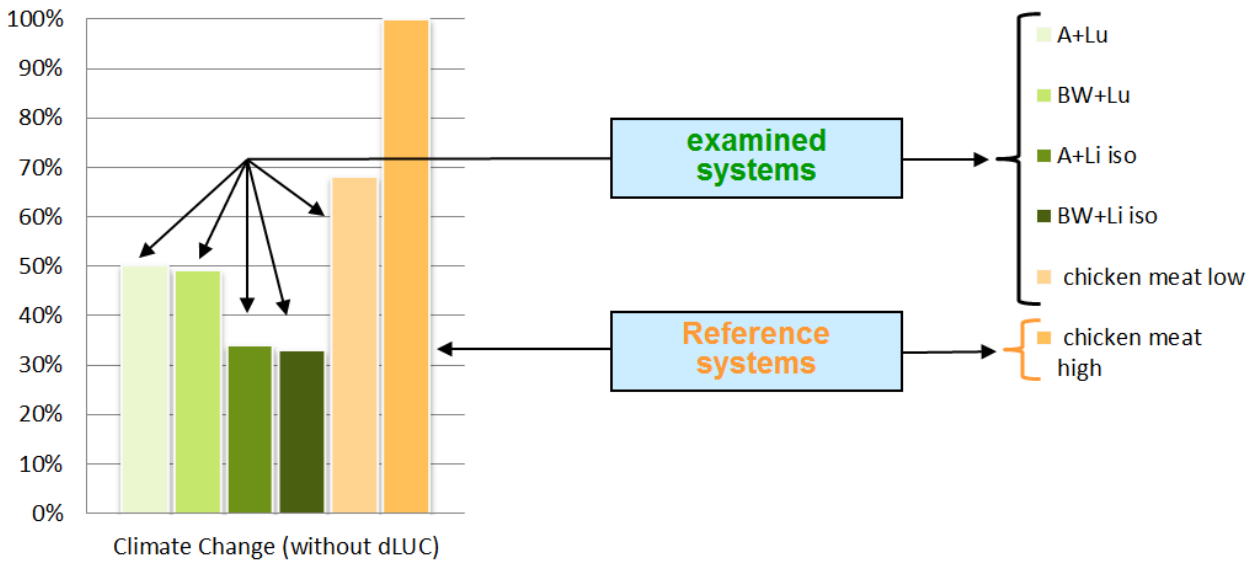

Figure 3-18: Format example for comparative results, indicator: Climate Change (without dLUC)

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3.2.1. Comparative results VMA-fiber (net result format, FU = protein)

The following figures (Figure 3-19 and Figure 3-20) illustrate comparative results of VMA-fiber versus traditional chicken meat divided into two parts (part 1 and part 2).

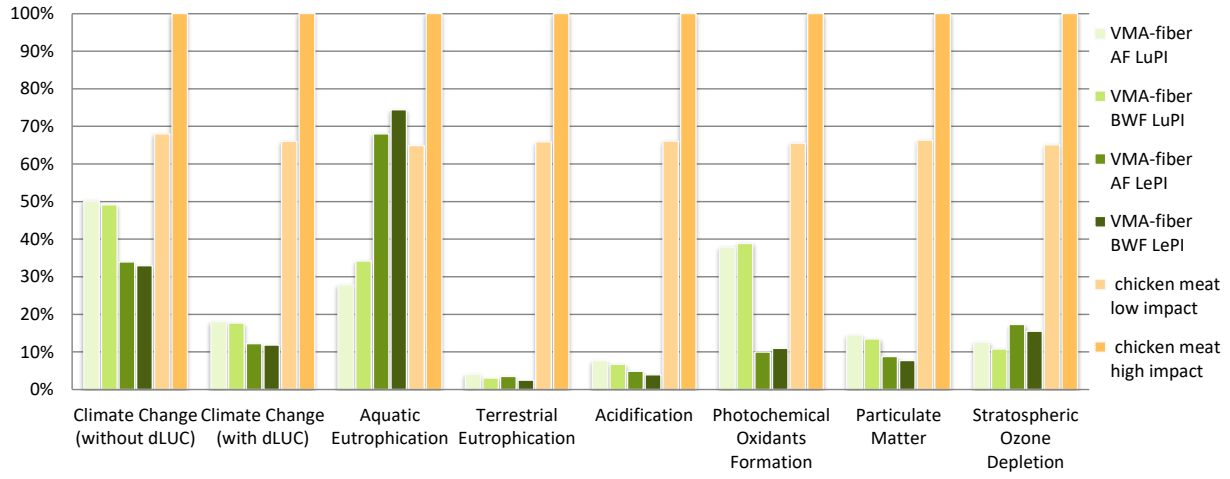

Figure 3-19: Comparative results VMA-fiber versus traditional chicken meat (part 1) (VMA: vegetable meat alternative, AF: amaranth flour, BWF: buckwheat flour, LuPI: lupin protein isolate, LePI: lentil protein isolate)

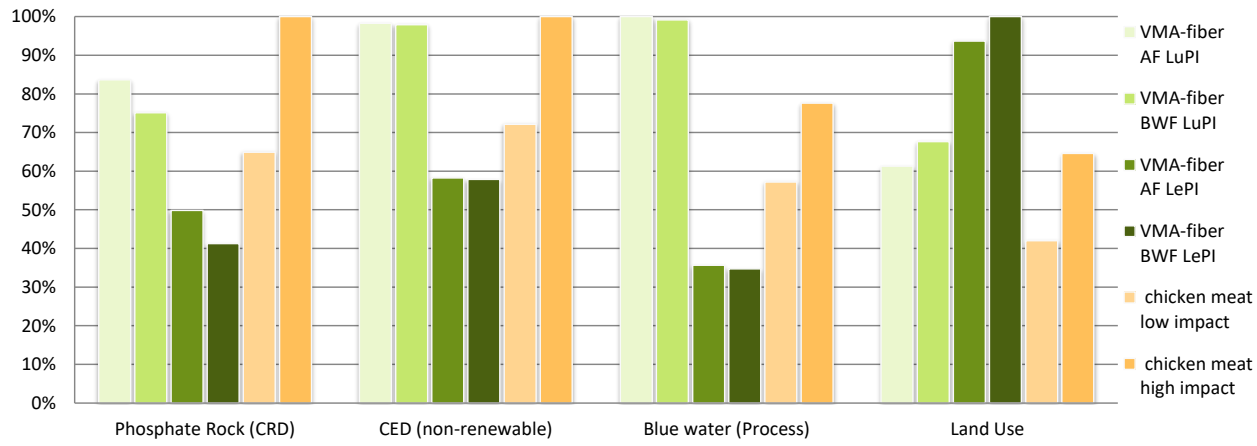

Figure 3-20: Comparative results VMA-fiber versus traditional chicken meat (part 2) (VMA: vegetable meat alternative, AF: amaranth flour, BWF: buckwheat flour, LuPI: lupin protein isolate, LePI: lentil protein isolate)

- Fig 3-19: seven out of eight indicators shown in this chart show that VMA-fiber prototypes are associated with lower environmental impacts than traditional chicken meat. In case of Aquatic Eutrophication, it depends on the seed type used to extract the protein isolate – lentil-based VMA-fiber is slightly over the "chicken low" results. This is for a good part related to the comparably low yields of lentils versus other crops, as e.g. the nitrate emissions to water (as main contributors to this indicator) are related to an area-based nitrogen balance. The latter is then transferred to a per kg crop basis, which means that

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high-yield crops tend to have lower specific nitrate emissions, even if overall nitrogen and nitrate amounts on the field are higher

- Fig 3-20: one out of four indicators shown in this chart (phosphate rock) shows lupin-based VMA-fiber is in between the chicken "low" and chicken "high" reference systems. Lentil-based VMA-fiber shows in three out of four indicators lower values than chicken low impact. In addition, VMA-fiber does not need non-renewable energy that is required in the chicken system for husbandry as well as slaughterhouse operations etc. On the other hand, lupin-based VMA-fiber requires process energy for a de-oiling step in order to separate oil and protein present in the lupin seeds, whereas this is not required for lentil-based VMA-fiber.

3.2.2. Comparative results VMA-spread (net result format, FU = protein)

The following figures (Figure 3-21 and Figure 3-22) illustrate comparative results of VMA-spread versus traditional (pork-based) Leberwurst (liver paté) spread divided into two parts (part 1 and part 2).

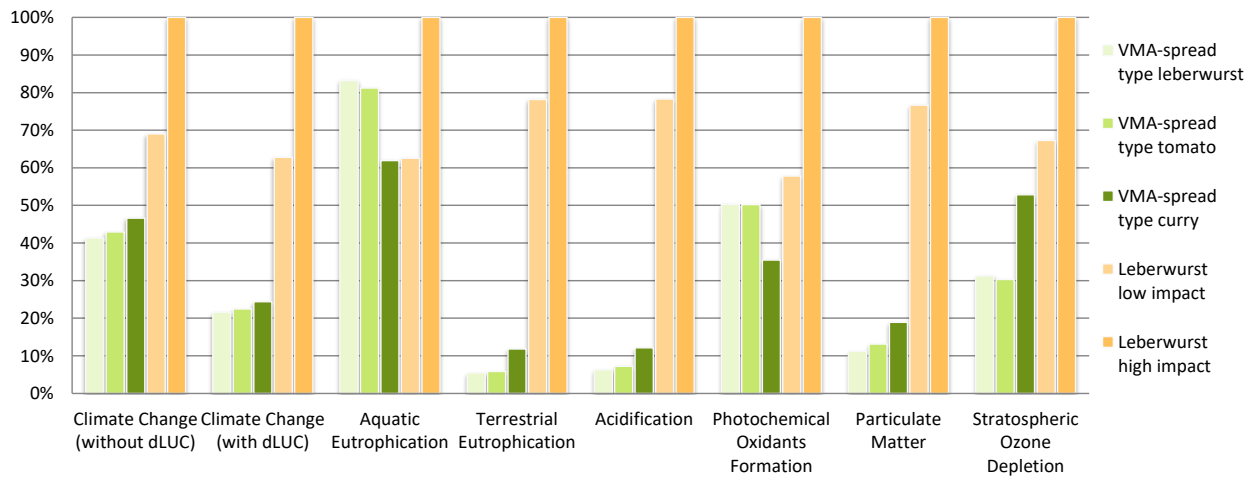

Figure 3-21: Comparative results VMA-spread versus traditional (pork-based) "Leberwurst" spread (part 1)

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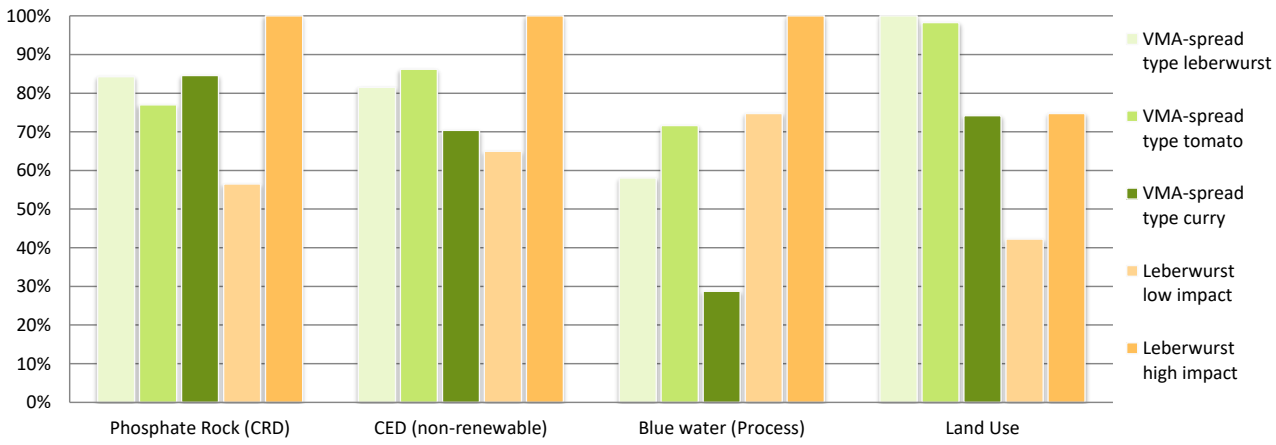

Figure 3-22: Comparative results VMA-spread versus traditional (pork-based) "Leberwurst" spread (part 2)

- Fig 3-21: seven out of eight indicators shown in this chart show that VMA-spread prototypes are associated with lower environmental impacts than traditional pork-based "Leberwurst" spread. In case of Aquatic Eutrophication, it depends on the addition of protein isolate or protein-rich flour as an alternative. Spread variant type curry is associated with lower Aquatic Eutrophication potentials than the other spread variants – if high-protein quinoa flour is used as an ingredient related potential impacts are comparable to the traditional "Leberwurst" spread variant "low"

- Fig 3-22: two out of four indicators (Phosphate rock, CED non-renewable) shown in this chart show a similar comparative result pattern: VMA-spread is in between the traditional "Leberwurst low impact" and"Leberwurst high impact" reference systems. In addition, water demand for process water use is lower for VMA-spread than for traditional "Leberwurst" reference systems. This is for a good part related to the relatively high process water demand in pig husbandry. The higher land use associated with VMA-spread types "Leberwurst" and "Tomato" is for a good part related to cultivation area for lupins as raw material for lupin protein isolate ingredient.

3.2.3. Comparative results vegetable Milk (net result format, FU = protein)

The following figures (Figure 3-23and Figure 3-24) illustrate comparative results of vegetable milk versus traditional cow milk divided into two parts (part 1 and part 2).

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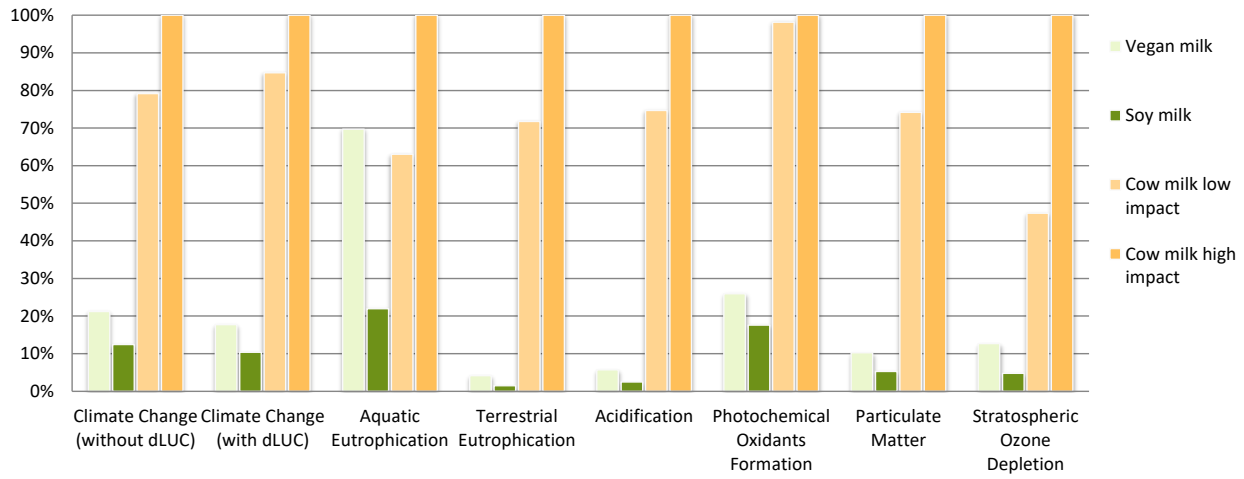

Figure 3-23: Comparative results vegetable milk versus traditional cow milk (part 1)

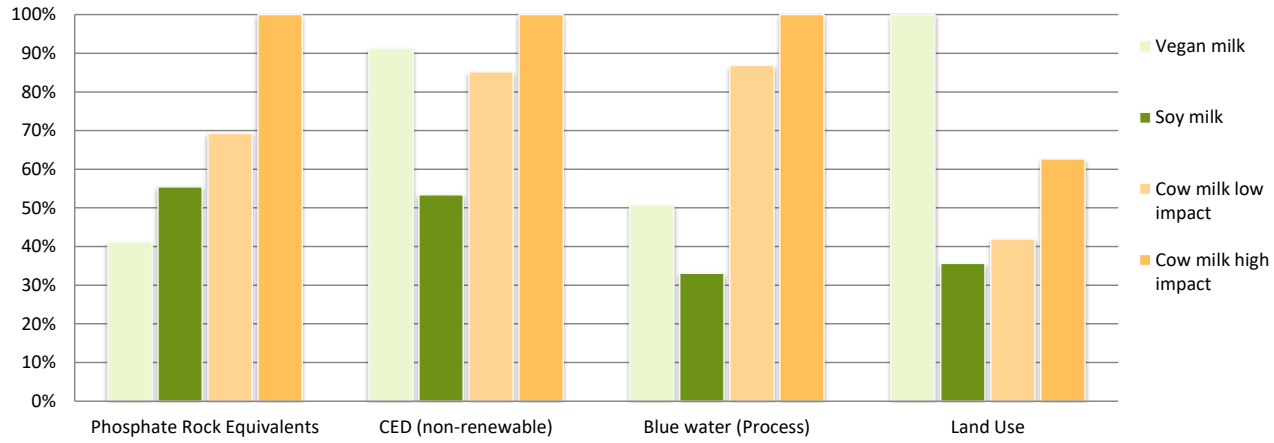

Figure 3-24: Comparative results vegetable milk versus traditional cow milk (part 2)

- Fig 3-23: seven out of eight indicators shown in this chart show that vegetable milk prototype is associated with lower environmental impacts than traditional cow milk. In case of Aquatic Eutrophication, vegetable milk is slightly higher than cow milk low impact.

- Fig 3-24: two out of four indicators (Phosphate rock, Blue water (Process)) shown in this chart show a similar comparative result pattern: Both vegetable milk and soy milk are lower than cow milk. On the other hand, CED non-renewable is slightly higher for vegetable milk versus cow milk low impact. Land Use of vegetable milk is however around double relative to chicken high impact. Here seems quite some improvement potential, if an increase in P2F crop yields may be achieved eventually.

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3.2.4. Comparative results vegetable Burger (net result format, FU= protein)

The following figures (Figure 3-25and Figure 3-26) illustrate comparative results of vegetable burger versus traditional beef burger divided into two parts (part 1 and part 2).

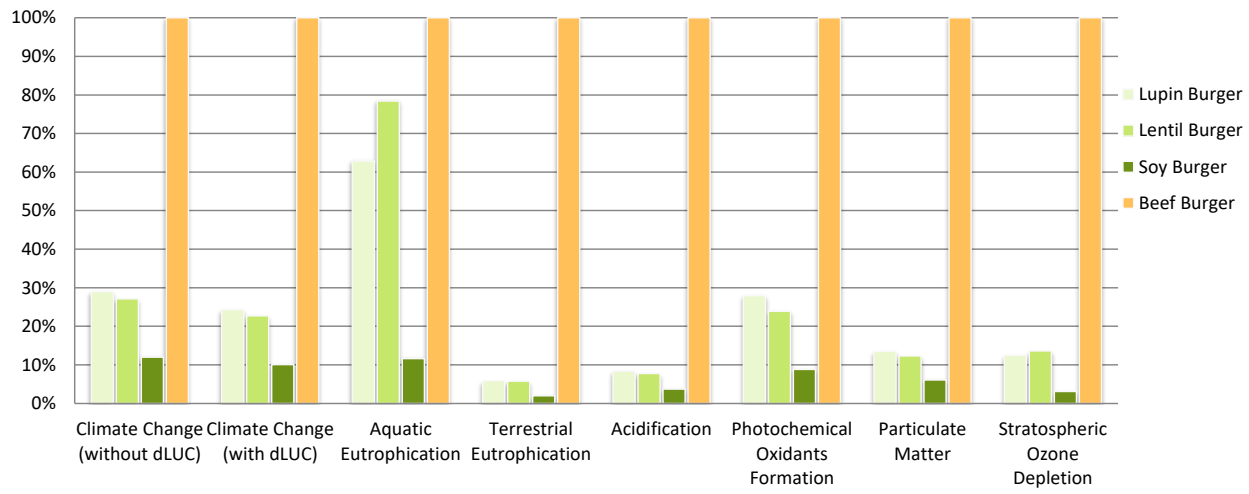

Figure 3-25: Comparative results vegetable burger versus traditional beef burger (part 1)

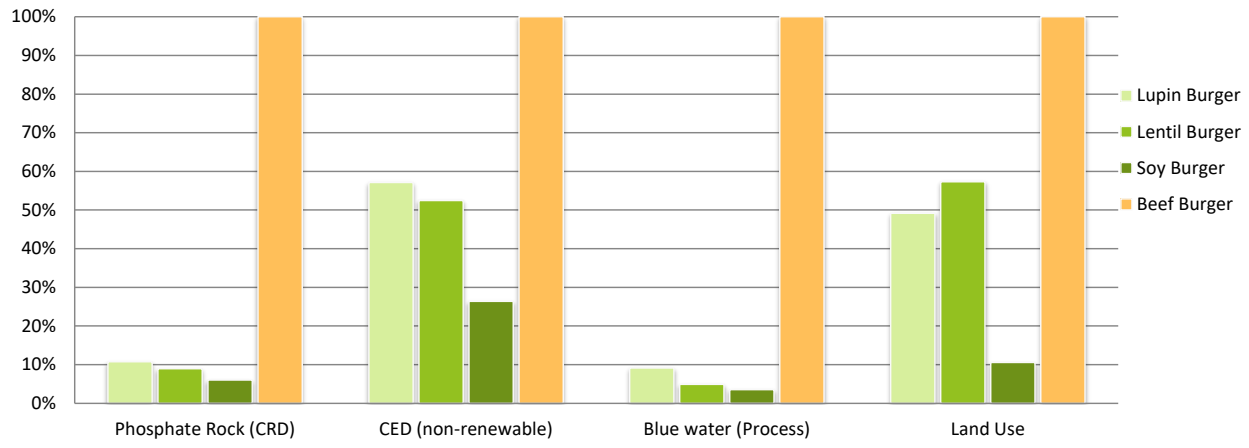

Figure 3-26: Comparative results vegetable burger versus traditional beef burger (part 2)

- Fig 3-25: eight out of eight indicators shown in this chart show that vegetable burger prototypes as well as soy burger are associated with lower environmental impacts than traditional beef burger.

- Fig 3-26: four out of four indicators shown in this chart show a similar comparative result pattern: Both vegetable burger and soy burger are lower than traditional beef burger.

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3.3. Condensed results over all indicators (FU = mass)

The following sections 3.3.1 to 3.3.4 illustrate condensed results (net results format) with the mas-based functional unit

3.3.1. Comparative results VMA-fiber (net result format, FU = mass)

The following figures (Figure 3-27 and Figure 3-28) illustrate comparative results of VMA-fiber versus traditional chicken meat divided into two parts (part 1 and part 2).

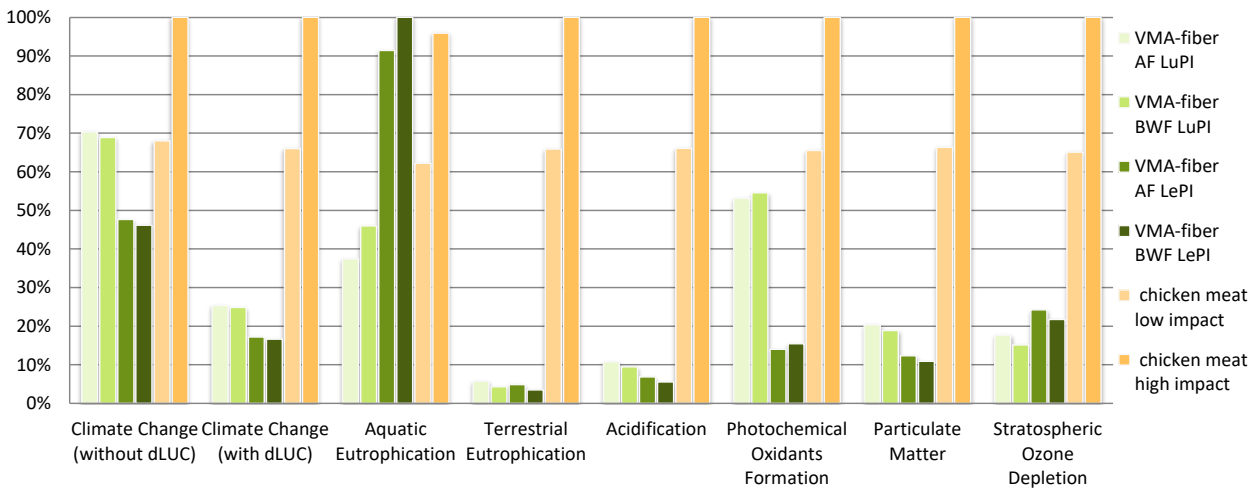

Figure 3-27: Comparative results VMA-fiber versus traditional chicken meat (part 1) (VMA: vegetable meat alternative, AF: amaranth flour, BWF: buckwheat flour, LuPI: lupin protein isolate, LePI: lentil protein isolate) FU: mass

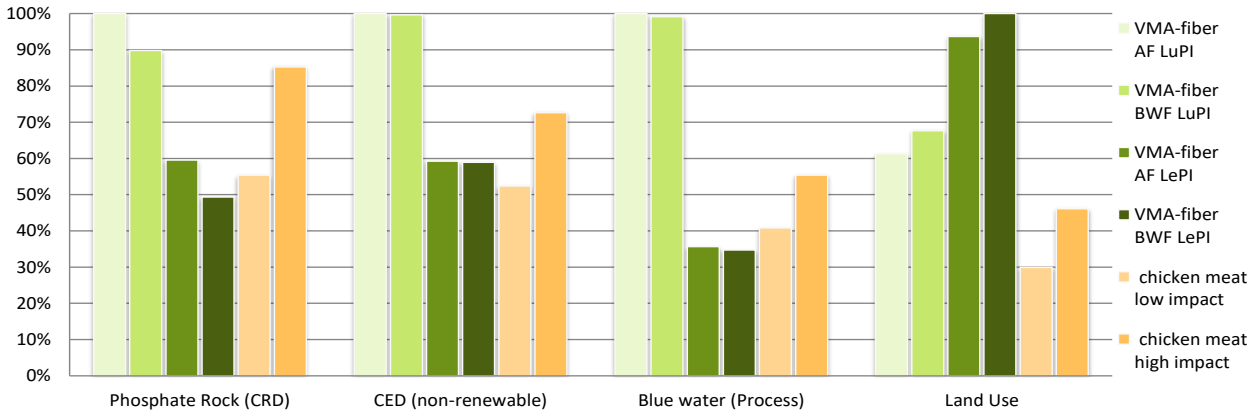

Figure 3-28: Comparative results VMA-fiber versus traditional chicken meat (part 2) (VMA: vegetable meat alternative, AF: amaranth flour, BWF: buckwheat flour, LuPI: lupin protein isolate, LePI: lentil protein isolate) FU: mass

- Fig 3-27: six out of eight indicators shown in this chart show that VMA-fiber prototypes are associated with lower environmental impacts than traditional chicken meat. In case of Aquatic Eutrophication, it depends on the seed type used to extract the protein isolate –

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lentil-based VMA-fiber is more in the range of "chicken high impact" results. This is for a good part related to the comparably low yields of lentils versus other crops, as e.g. the nitrate emissions to water (as main contributors to this indicator) are related to an area-based nitrogen balance. The latter is then transferred to a per kg crop basis, which means that high-yield crops tend to have lower specific nitrate emissions, even if overall nitrogen and nitrate amounts on the field are higher. On the other hand, lentil-based VMA-fiber is associated with less greenhouse gas emissions than chicken meat, even if direct land use change effects (for chicken feed crops) are not taken into consideration.

- Fig 3-28: Lentil-based VMA-fiber shows in three out of four indicators values in the range of chicken low impact. Lupin-based VMA-fiber on the other hand is above the chicken meat reference system. This is again related to the process energy required for a de-oiling step in order to separate oil and protein present in the lupin seeds, whereas this is not required for lentil-based VMA-fiber.

3.3.2. Comparative results VMA-spread (net result format, FU = mass)

The following figures (Figure 3-29 and Figure 3-30) illustrate comparative results of VMA-spread versus traditional Leberwurst spread (liver paté) divided into two parts (part 1 and part 2).

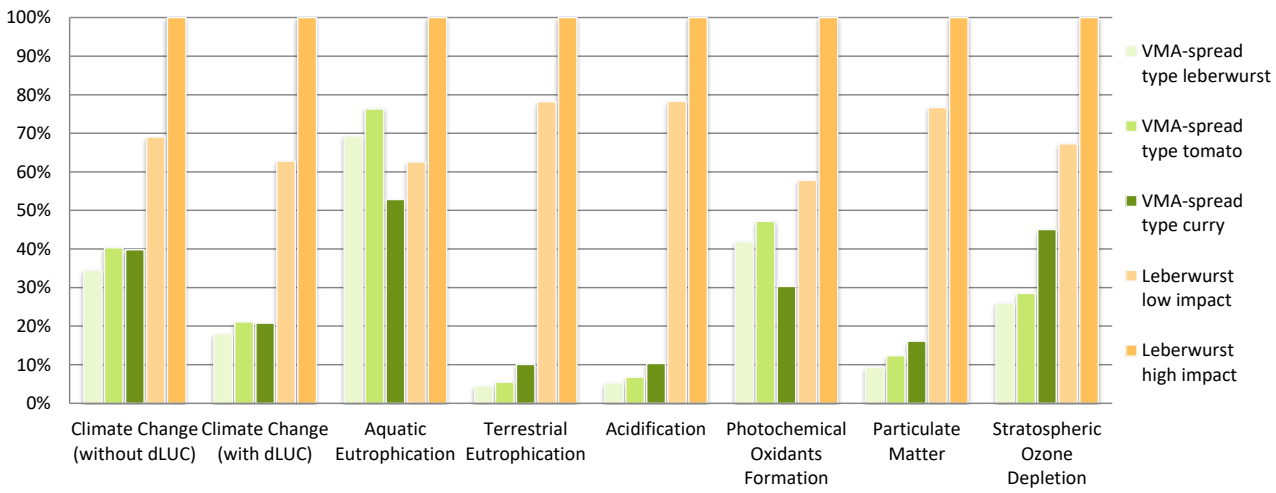

Figure 3-29: Comparative results VMA-spread versus traditional (pork-based) "Leberwurst" spread (part 1) FU: mass

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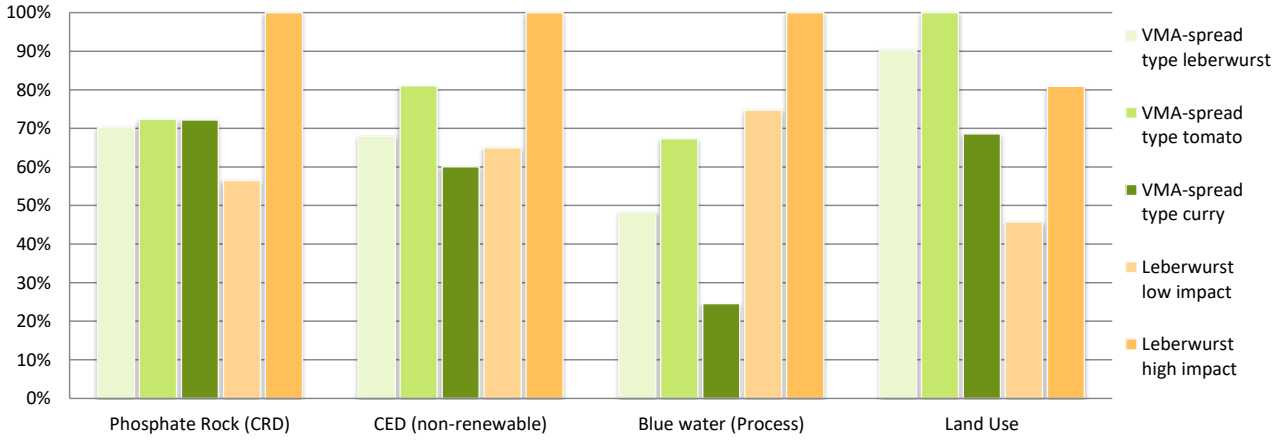

Figure 3-30: Comparative results VMA-spread versus traditional pork-based "Leberwurst" spread (part 2) FU: mass

- Fig 3-29: seven out of eight indicators shown in this chart show that VMA-spread prototypes are associated with lower environmental impacts than traditional pork-based "Leberwurst" spread. In case of Aquatic Eutrophication, it depends on the addition of protein isolate or protein-rich flour as an alternative. Spread variant type curry is associated with lower Aquatic Eutrophication potentials than the other spread variants – if high-protein quinoa flour is used as an ingredient related potential impacts are comparable to the traditional "Leberwurst" spread "low impact".

- Fig 3-30: two out of four indicators (Phosphate rock, CED non-renewable) shown in this chart show a similar comparative result pattern: VMA-spread is in between the traditional "Leberwurst low impact" and "Leberwurst high impact" reference systems. In addition, water demand for process water use is lower for VMA-spread than for traditional "Leberwurst" reference systems. This is for a good part related to the relatively high process water demand in pig husbandry. The higher land use associated with VMA-spread types "Leberwurst" and "Tomato" is for a good part related to cultivation area for lupins as raw material for lupin protein isolate ingredient.

3.3.3. Comparative results vegetable Milk (net result format FU = mass)

The following figures (Figure 3-31 and Figure 3-32) illustrate comparative results of vegetable milk versus traditional cow milk divided into two parts (part 1 and part 2).

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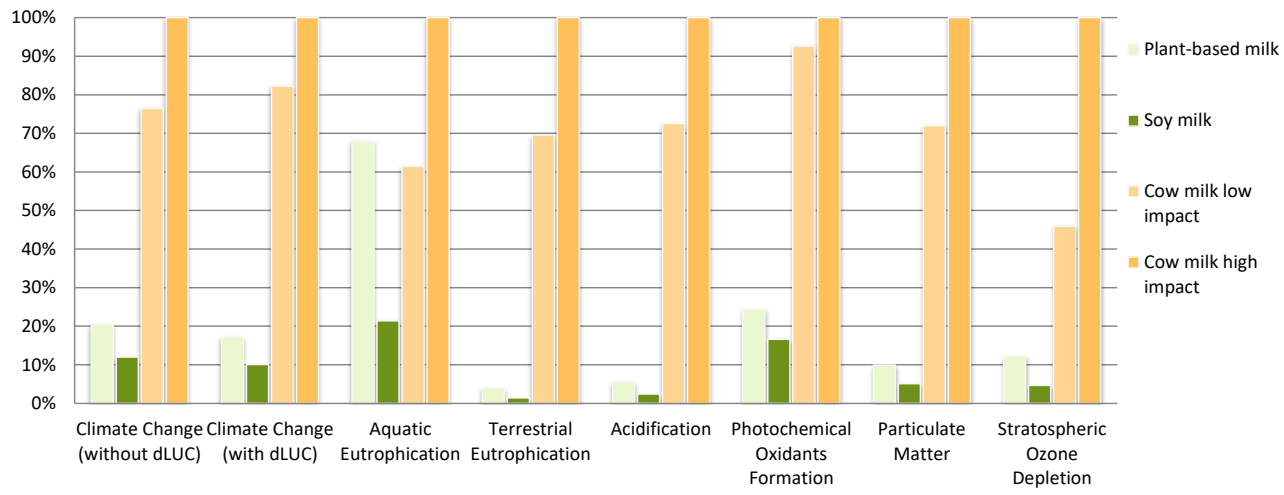

Figure 3-31: Comparative results vegetable milk versus traditional cow milk (part 1) FU: mass

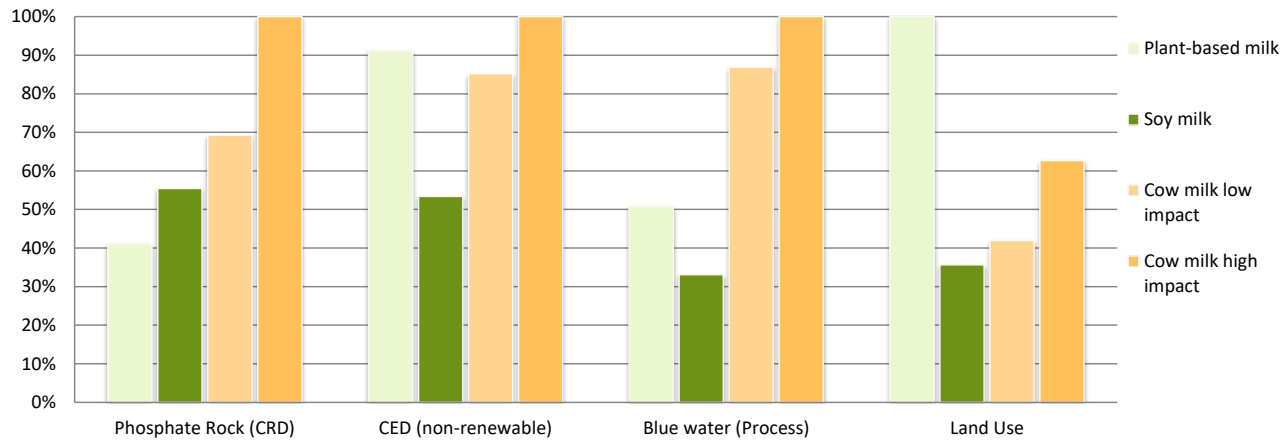

Figure 3-32: Comparative results vegetable milk versus traditional cow milk (part 2) FU: mass

- Fig 3-31: seven out of eight indicators shown in this chart show that vegetable milk prototype is associated with lower environmental impacts than traditional cow milk. In case of Aquatic Eutrophication, vegetable milk is slightly higher than cow milk low impact.

- Fig 3-32: two out of four indicators (Phosphate rock, Blue water (Process)) shown in this chart show a similar comparative result pattern: Both vegetable milk and soy milk are lower than cow milk. On the other hand, CED non-renewable is slightly higher for vegetable milk versus cow milk low impact. Land Use of vegetable milk is however around double relative to chicken high impact. Here seems quite some improvement potential, if an increase in P2F crop yields may be achieved eventually.

3.3.4. Comparative results vegetable Burger (net result format, FU= mass)

The following figures (Figure 3-33 and Figure 3-34) illustrate comparative results of vegetable burger versus traditional beef burger divided into two parts (part 1 and part 2).

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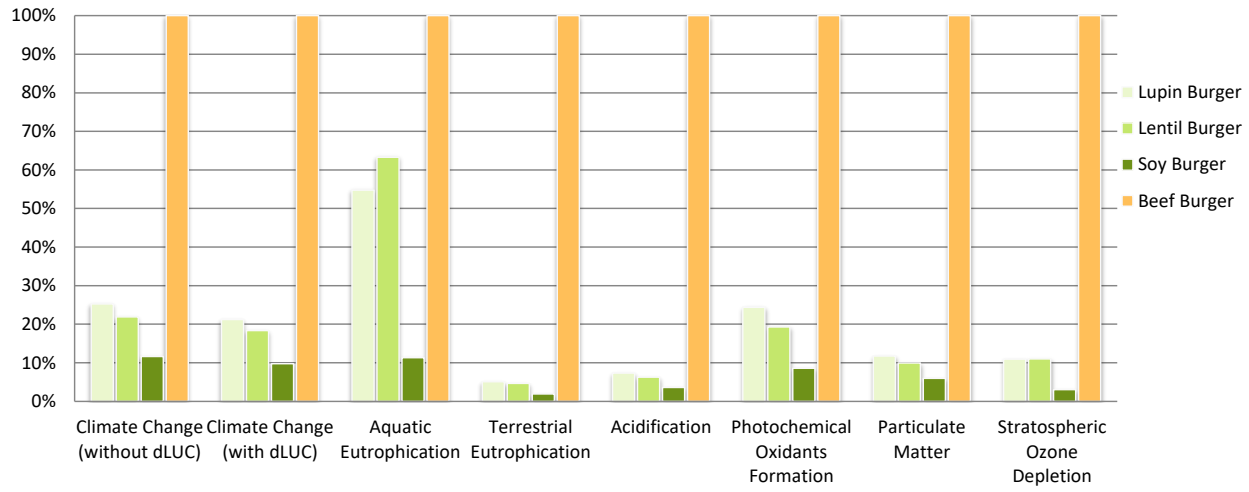

Figure 3-33: Comparative results vegetable burger versus traditional beef burger (part 1) FU: mass

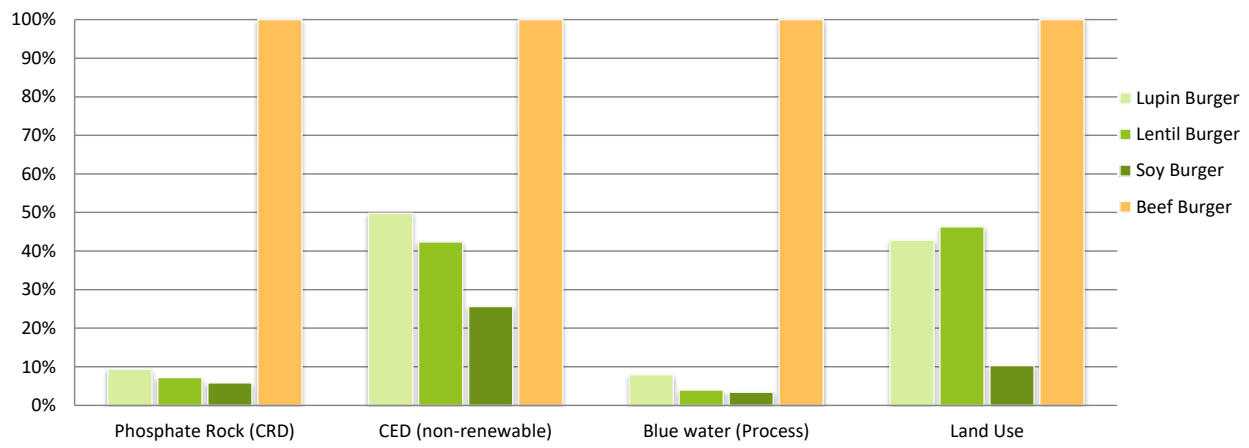

Figure 3-34: Comparative results vegetable burger versus traditional beef burger (part 2) FU: mass

- Fig 3-25: eight out of eight indicators shown in this chart show that vegetable burger prototypes as well as soy burger are associated with lower environmental impacts than traditional beef burger.

- Fig 3-26: four out of four indicators shown in this chart show a similar comparative result pattern: Both vegetable burger and soy burger are lower than traditional beef burger.

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