Supplementary Material

February 2020

Contents

1 Detailed methodology

1.1 Demand

1.1.1 Base demand

Annual per capita food consumption in Germany was used to estimate the demand in BW. Wherever possible, consumption data for the year 2015 from the statistical yearbook for food, agriculture and forests in Germany BMEL (2016) was used. Based on three criteria a food basket that represents German consumption was created:

1. Can the product be grown in BW?

2. Is the product relevant in terms of food security ?

3. Can the product be produced on arable land and pasture (the two major land use types in BWs agriculture)?

Table 2 shows which of the listed products were used in this study.
Fish, rice, cacao and citrus fruits were not included because they cannot be produced properly in BW. Fruits and nuts were not included because they cannot be grown on pasture or arable land. As compensation the agricultural land was diminished by the area that would be needed to produce the demand for fruits. Other cereals are of minor concern compared to wheat and rye. The considered vegetables products represent approximately 80% of their total demand (fruits were excluded for calculating this value because the diminished agricultural land accounts for their production). About 15 % (13.5 kg) of meat consumption is covered by beef and veal, 59 % (52.1 kg) by pork, and 22 % (19.8 kg) by poultry. The remaining four percent are made up of game and rabbit, sheep and goat meat, and innards. Fish is not considered in this study. The amount of fish and fish products consumed is approximately equivalent to the amount of beef and veal consumed. The total amount of milk consumed in the form of milk equivalent was not taken from the statistical yearbook but another source provided by the German administration BLE (2019). The considered products represent approximately 90 % of the meat demand and 100 % of the demand for milk products, and eggs. Further processing of agricultural raw products leaving the farm were not considered. Hence, the demand for food products was defined as amounts of agricultural food products at farm gate. In many cases the per capita demand stated in the statistical yearbook does not correspond to the food products' weight at farm gate but to consumed end products. In these cases the demand values had to be converted to represent the demand used in this study: The weight for Wheat and rye are given in flour values and was converted to represent the whole grain at farm gate. The demand for sugar, which is assumed to come from sugarbeets, was converted to fit the demanded amount of the crop. The same applies for plant based oil and potato starch. The food category vegetables was divided into the three subcategories root vegetables, leafy vegetables and other vegetables, which are represented in this study by carrots, lettuce and tomatoes. The proportion of these subcategories were taken from Destatis (2016). Beef, pork and poultry are listed in slaughter weight and were multiplied with conversion factors to yield edible weight at farm gate. Lastly, waste losses along the supply chain were added to the converted demand by multiplying it with waste loss factors, to really depict how much of a product needs to be produced so that a sufficient amount reaches the consumer. Table 1 gives an overview of the factors used for accounting for conversion and waste losses.

Table 1: Shows conversion factors (cf.) and waste loss factors (lf.) for the used products. The source for each conversion loss is given in the source column, waste losses are all taken from Eberle and Fels (2016)

conversion	conversion loss	source	waste loss	cf.	lf.
Wheat to wheat flour	24%	KTBL (2009)	19%	$\frac{1}{0.76}$	$\frac{1}{0.81}$
Rye to Rye flour	24%	KTBL (2009)	19%	$\frac{1}{0.76}$	$\frac{1}{0.81}$
Soybean to Legumes	0%		29%	1	$\frac{1}{0.71}$
Potato to Potato	0%		29%	1	$\frac{1}{0.71}$
Potato to Potato starch	80%	ISI (2017)	29%	$\frac{1}{0.2}$	$\frac{1}{0.71}$
Sugarbeet to sugar	84%	FAO (2009)	19%	$\frac{1}{0.16}$	$\frac{1}{0.81}$
Vegetables to Vegetables	0%		29%	1	$\frac{1}{0.71}$
Oilseeds to oil	77%	FAO (2010)	21%	$\frac{1}{0.23}$	$\frac{1}{0.79}$
Beef (sl.) to beef (ed.)	31%	Nijdam et al. (2012)	0%	0.69	1
Pork (sl.) to pork (ed.)	25%	Nijdam et al. (2012)	0%	0.75	1
Poultry (sl.) to poultry (ed.)	21%	Nijdam et al. (2012)	0%	0.79	1

Table 2: Shows German per capita consumption of food products. The demand values given by BMEL are converted so that they fit the crops used in this study by multiplying them with corresponding conversion factors. Waste losses along the supply chain are accounted by multiplying the converted demand with corresponding waste loss factors. The abbreviation dm. denotes for demand, cf. stands for conversion factor and lf. for waste loss factor. The proportion for the vegetables' subcategories (carrots, lettuce, tomatoes) were taken from Destatis (2016)

product (BMEL)	dm. (BMEL)	represented in this study by	cf.	dm. converted	lf.	dm. farm gate
Wheat (flour value)	64.6	Wheat	1.32	85	1.23	104.9
Rye (flour value)	8	Rye	1.32	10.5	1.23	13
Legumes	0.9	Soybean	1	0.9	1.4	1.3
Potatoes	58	Potatoes	1	58	1.4	81.7
Potato starch	13.7		5	68.5	1.4	96.5
Sugar	33.6	Sugarbeet	6.25	210	1.23	258.3
Vegetables	98.6	Carrots	1	46.18	1.4	64.91
		Lettuce	1	24.92	1.4	35.02
		Tomatoes	1	27.5	1.4	38.66
Plant based oil	14.5	Sunflower, Rapeseeed	4.39	63.4	1.28	80.5
Beef (slaughter weight)	13.5	Beef (edible weight)	0.69	9.4	1	9.4
Pork (slaughter weight)	52.1	Pork (edible weight)	0.75	39.1	1	39.1
Poultry (slaughter weight)	19.8	Poultry (edible weight)	0.79	15.7	1	15.7
Eggs	14.4	Eggs	1	14.4	1	14.4
Milk	402	Milk	1	402	1	402
Rice	5.4	-	-	-	-	-
Cacao	3.5	-	-	-	-	-
Other cereals	6.4	-	-	-	-	-
Fruits	66.5	-	-	-	-	-
Citrus fruits	35.1	-	-	-	-	-
Nuts	4.7	-	-	-	-	-
Sheep	0.9	-	-	-	-	-
Horse	0	-	-	-	-	-
Innards	0.7	-	-	-	-	-
Fish	16	-	-	-	-	-

1.1.2 Alternative diets

In many studies the need for a shift in diets to mitigate environmental impacts and for health reasons is stressed. Meier and Christen (2013) consider different diets for Germany in their study. They include one diet based on recommendations of the German Nutrition Society, "Deutsche Gesellschaft für Ernährung" (DGE), a vegetarian, and a vegan diet. We took the relative changes of the vegetarian and vegan diets compared to the diet considered as base scenario in Meier and Christen (2013) to convert the base demand presented in this study into these alternative diets. Table 3 shows the different diets for this study on a per capita basis. Furthermore, it shows the relative changes of the adapted diets compared to the base diet.

Table 3: Shows the three different demand scenarios and the percental change (amendment) from the base demand. The abbreviation veget. stands for vegetarian

category	base [kt]	amendment veget.[%]	vegetarian [kt]	amendment vegan [%]	vegan [kt]
carrots	64.9	6.0	68.8	6.0	68.8
lettuce	35.0	6.0	37.1	6.0	37.1
oil	80.5	79.7	147.1	126.3	184.8
potato	178.2	33.7	238.70	33.7	238.7
rye	13.0	6.2	13.8	6.2	13.8
soybean	1.3	3384.6	45.3	5546.2	73.4
sugarbeet	258.3	-54.4	118.3	-54.4	118.3
tomatoes	38.7	5.9	41.0	5.9	41.0
wheat	104.9	5.7	111.4	5.7	111.4
beef	9.4	-100.0	0.0	-100.0	0.0
egg	14.4	-11.1	12.8	-100.0	0.0
milk	401.9	3.2	414.0	-100.0	0.0
pork	39.1	-100.0	0.0	-100.0	0.0
poultry	15.7	-100.0	0.0	-100.0	0.0

1.2 Life cycle assessment (LCA)

LCAs were used to quantify the environmental impacts associated with the production of the selected agricultural products. LCA is a standardized method (ISO 14040 and 14044) to quantify resource needs and emissions of goods and services. It consists of four standard phases: Goal and scope definition, life cycle inventory (LCI) analysis, life cycle impact assessment (LCIA), and interpretation. The goal defines the intent of the LCA. The scope specifies the extent of the study, including the system boundary of the studied product system and the functional units. In the inventory analysis, physical flows to and from a product or process are assessed and allocated to the functional unit (FU). The LCIA translates the physical flows allocated to the FU into environmental impacts using characterization factors. Rather than conducting our own LCAs for ever product, We used existing LCIs from the AGRIBALYSE database. The AGRIBALYSE v1.3 database offers LCIs for many conventional and organic production processes, from cradle to farm gate. The geographical scope of the database is the French agricultural product system, which we considered an acceptable approximation for production conditions in BW, due to the relative geographical proximity. Furthermore, the LCIs are well documented and the data is open source. AGRIBALYSE uses the Ecoinvent v3.2 database for upstream (non-agriculture) LCIs. AGRIBALYSE v1.3 did not include all required production processes. LCIs of missing processes were approximated, using existing AGRIBALYSE LCIs and information about BW agriculture. Furthermore, some adaptations were made to the used AGRIBALYSE LCIs to fit BW production processes. To assess the LCIs and to calculate the life cycle impact assessments (LCIAs), we used the open source LCA software openLCA. In the following, the study design parameters for the LCAs are described in further detail.

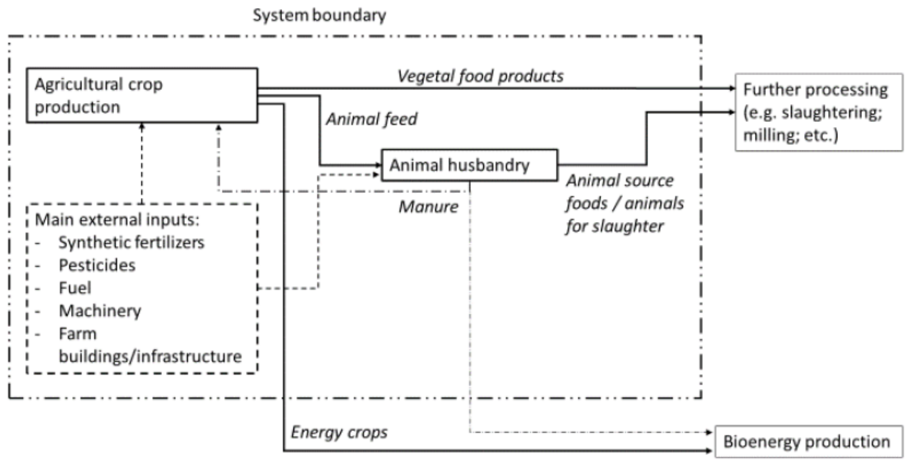

Figure 1: System boundaries for the LCA

1.2.1 Scope

The product system of the LCAs is the agricultural product system in BW with all agricultural production stages within the geographical boundaries of BW. 1 shows the system boundary, cradle-to-farm gate, (in coherence with the system boundary used in the AGRIBALYSE LCIs) of this product system. It includes the agricultural production of crops (food and feed use) and livestock and all up-stream inputs. It does not include any further processing of these products (e.g., milling or slaughtering). Furthermore, bioenergy production is excluded from the system. Not all LCAs necessarily include all aspects of the product system (e.g., food crops). The temporal frame regarding demand and production is one year.

1.2.2 Functional units

The functional unit (FU) for all products is 1 kiloton (kt) of product 2 , The FU of crops, milk and eggs is further specified according to the definition in the AGRIBALYSE database:

- Arable crops: "[kt] of whole matter to the standards required (moisture, sugar, protein contents) of the product at the farm gate".
- Milk: "[kt] of milk corrected to 4% fat and 3.3% protein".
- Eggs: [kt], including shell

The FU for meat products is kg of live weight in AGRIBALYSE. In this study, kt of edible weight is used as FU for meat products.

1.2.3 LCIs of livestock production in BW

To keep data requirements within reasonable limits, a selection of livestock production processes had to be made. Based on the information gathered on cattle, pig and poultry rearing systems and on the demands in BW, general livestock production processes were selected to represent BW livestock production in the MO. Although, organic production only represents a small share of livestock production in BW, it was included in this study as an alternative to the conventional production system. For milk and beef production, pasture and arable land based processes were considered. For pig rearing, only two processes, one conventional and one organic, were considered, due to the difficulty in clearly distinguishing different production processes based on feed diets. Egg production is represented by the most common rearing type, indoor free-run. Broiler and turkey production was included because poultry demand is increasing and constitutes a significant share of the demand for meat.

Figure 2: LCI selection for livestock

Livestock (product)	Conventional/ Organic	Rearing system	AGRIBALYSE LCI[a]
Dairy cows (milk + cull cow (beef))	Conventional	Pasture	"Cow milk, conventional, highland milk system, grass fed" + "Cull cow, conventional, highland milk system, grass fed"
	Conventional	Arable land	"Cow milk, conventional, lowland milk system, silage maize more than 30 %" + "Cull cow, conventional, lowland milk system, silage maize more than 30 %"
	Organic	Pasture[b]	"Cow milk, organic, lowland milk system, silage maize 5 to 10 %" + "Cull cow, organic, lowland milk system, silage maize 5 to 10 %"
	Organic	Arable land[b]	
Cattle (beef)	Conventional	Pasture	-
	Conventional	Arable land	"Young dairy bull, conventional, fattening system"
	Organic	Pasture	-
	Organic	Arable land	-
Pigs (pork)	Conventional		"Pig, conventional, on-farm feed supply" + "Cull sow, conventional, on-farm feed supply"
	Organic		"Pig, organic" + "Cull sow, organic"
Laying hens (Eggs + cull hen (poultry))	Conventional	Indoor, free-run	"Egg, conventional, indoor system, non-cage" + "Cull hen, conventional, indoor system, non-cage"
	Organic	Indoor, free-run	"Egg, organic" + "Cull hen, organic"
Broiler (poultry)	Conventional	Indoor, free-run	Broiler, conventional
	Organic	Indoor, free-run	Broiler, organic
Turkey (poultry)	Conventional		Turkey, conventional
	Organic		-

To match the selected livestock production processes with LCIs, the available LCIs in AGRIBALYSE were screened and the LCIs representing the desired BW production processes best, based on feed used, rearing system (e.g., pasture based), and performance figures (e.g., annual milk yield), were selected. Not all desired production processes could be covered that way. Covering the missing processes with LCIs from other studies or databases would most likely lead to inconsistencies in how the LCIs were conducted. Therefore, we created proxy LCIs based on the available AGRIBALYSE LCIs and further information about BW agricultural production for the missing LCIs. For organic milk production, only one LCI was available in AGRIBALYSE. This LCI represents a rather intermediate production process regarding feed from pasture and arable land. Thus, organic milk production was not further differentiated in pasture and arable land based production. However, for organic bull fattening, two proxy LCIs were created: one pasture and one arable land based fattening process. Furthermore, proxy LCIs for a conventional pasture based bull fattening process and organic turkey production were created.

The equivalent conventional LCIs were taken and the conventional feedstuff inputs replaced by equivalent organic feedstuffs (where equivalent organic feedstuff LCIs were available in AGRIBALYSE). The amount of feed and all other variables were left unchanged. In the case of the two pasture-based bull fattening processes, conventional and organic, we calculated the energy content of the total feed in the process "Young dairy bull, conventional, fattening system". Then, we replaced the feed in the existing LCI "Young dairy bull, conventional, fattening system" with a feed diet for grassland based bull (ox), so that the total energy content of the new diet (once conventional and once organic) stayed the same as the energy content of the original diet. Bull fattening is the dominant beef production type, however, the fattening of heifers is also used to produce beef. This was approximated in the model by bull fattening.

1.2.4 Handling of co-products

In AGRIBALYSE allocation between co-products was avoided as far as possible "by dividing the [animal production] process into several unit processes, breaking the life of the animal down into characteristic development stages" (e.g., calf from birth to weaning, replacement heifer weaning to age of one year, etc.). However, where allocation is not avoidable (e.g., milk production stage, when calves and milk are "produced" at the same time), a "bio-physical" allocation approach was used for livestock production processes 4 . Impacts were allocated to the products and co-products according to the "energy required for the various physiological functions of the animal and to produce the product and co-products". In the final process LCIs in AGRIBALYSE, for example, "Cull cow, conventional, highland milk system, grass fed", the animal development stage unit processes were combined again according to the aforementioned allocation. For the model in this study, we used a system expansion approach regarding product and co-products of livestock production processes. This way, the production of main product (e.g., milk) and co-products (e.g., beef) was directly coupled and treated as one process. Beef (from cull cows and fattened bulls) was produced as a co-product of milk. Because organic bull fattening was differentiated between an arable land and a pasture based process, two organic milk production processes were also considered. However, the difference of the two organic milk production processes lies only in the bull fattening process. Egg production also includes the co-product poultry from cull hens. The ratios of product and co-products produced within one process I took from the AGRIBALYSE v1.3 database. For broiler and turkey production no co-products were considered in AGRIBALYSE. The LCIs for the new system expansion based processes were not added to the AGRIBALYSE database in openLCA, but LCAs were calculated for the given AGRIBALYSE products and added later to form one LCA as described by the system expansion approach.

1.2.5 LCIs of food crops

The LCIs for food crops we took from AGRIBALYSE v1.3 and applied an adaptation of the electricity mix (see below). No LCIs were available in AGRIBALYSE for conventional lettuce and rye, and organic lettuce, potato, rapeseed, rye, spring pea, and sugar beet. Therefore, We chose proxies as stand-in for the required data. This should be considered when interpreting the results. The impacts of feed crop production were covered by the livestock LCIs and therefore not needed as separate input for the MO.

1.2.6 German Electricity Mix

One adaptation, applied to all considered LCIs, was the replacement of the French low voltage electricity mix with the German low voltage electricity mix. This was achieved by adapting the used Ecoinvent v3.2 background database. The process "market for electricity, low voltage — electricity, low voltage — cut-off, U – FR" was replaced with "market for electricity, low voltage — electricity, low voltage — cut-off, U – DE" by changing inputs/outputs of process "market for electricity, low voltage — electricity, low voltage — cut-off, U - FR" by deleting all given inputs and outputs except 1 kWh electricity and replace with the input 1 kWh "market for electricity, low voltage — electricity, low voltage — cut-off, U – DE". However, this change did not affect the few processes where only the cumulative LCIs were available (contrary to unit processes, majority of processes).

1.2.7 Impact factors

Table 4: Shows environmental impacts per kiloton of product. The subscribt o and c stand for organic and conventional. The subscribt a and p for milk stand for arab fed and pasture fed.

	CC [kg CO2 / kt]	**ME [kg N-eq. / kt]**	**TAC [kg SO2-eq. / kt]**	**TET [kg 1,4-DCB-eq. / kt]**
carrots_o	33890.5	17.3233	260.58725	3.9
carrots_c	49201.4	843.24568	304.7731	319000
lettuce_o	33890.5	17.3233	260.58725	3.9
lettuce_c	49201.4	843.24568	304.7731	319000
potato_o	51689.64	693.83507	985.8777	760
potato_c	51689.64	693.83507	985.8777	760
rapeseed_o	520859	10557.3	11887.1	72900
rapeseed_c	520859	10557.3	11887.1	72900
rye_o	215791.9	944.7735	1105	-204
rye_c	236886	4750.8324	6011.78331	10400
soybean_o	484062	12700	1951.25260	26.30401
soybean_c	335526	9198.1794	2050.7796	163.6799
sugarbeet_o	23905.1	263.06902	535.1335	500
sugarbeet_c	23905.1	263.06902	535.1335	500
sunflower_o	409406.5	12528.95	6804.58	3350
sunflower_c	347904	10873.2	5827.38525	43700
tomatoes_o	208171	187.6399	1373.15385	41.4
tomatoes_c	2225950	1963.10177	5569.30583	160
wheat_o	215791.9	944.7735	1105	-204
wheat_c	236886	4750.8324	6011.78331	10400
broiler_o	2400970.8	46085.82	118848.97	9950
broiler_c	1447288.62	13045.65	69514.06	73400
egg_o	1503157.55	21682.53	58849.96	9950
egg_c	1476833.13	12222.43	78759.3	52500
pig_o	5785782.52	57943.41	150100.07	612
pig_c	3104749.62	23189.28	101045.3	74800
turkey_o	1819866	37065	87360	46700
turkey_c	1786092.56	20770.22	99322.87	138000
milk_o_p	1276130	6914	20731	372
milk_c_p	1790118	4385	27461	4970
milk_o_a	1239406	7483	20818	363
milk_c_a	968673	4255	14902	9470

Figure 3: Changed inputs for arable fed organic bulls

Flow	Unit	Amount old[a]	Amount new	% of total feed
Baled hay, temporary meadow, with clover, Northwestern regions, at feeder[b]	kg	215.1	215.1	8.69
Bovine feed, CMV 5-25-5, at farm gate[c]	kg	87.5	87.5	3.54
Bovine feed, suckler feed, at farm gate[d]	kg	41.8	41.8	1.69
Conventional lowland milk system, silage maize more than 30%, animal class 1, at farm	Item(s)	0.03	0.03	-
Dairy cow building, full straw-spread byre, mostly wood (lowland)	Item(s)	1.0	1.0	-
electricity, low voltage | market for electricity, low voltage	kWh	149.9	149.9	-
heat, central or small-scale, other than natural gas | heat production, light fuel oil, at boiler 100kW condensing, non-modulating	MJ	617.2	617.2	-
Silage maize, conventional, national average, at feeder	kg	1121.4	-	-
Silage maize, organic, Switzerland national average, at farm gate - CH	kg	-	1121.4	45.32
Soft wheat grain, conventional, national average, animal feed, at farm gate, production	kg	478.7	-	-
Soft wheat grain, organic, 15% moisture, Central Region, at farm gate - FR	kg	-	478.7	19.35
Soybean meal BR, crushing in Brazil, animal feed, at french port, average	kg	529.9	-	-
Soybean meal, organic, Italy national average, at feed plant - FR	kg	-	529.9	21.41
Suckler cattle building, full straw-spread byre, mostly wood	Item(s)	1.0	1.0	-
tap water | market for tap water	kg	16170.6	16170.6	-
Wheat straw (empty process)	kg	1202.0	1202.0	-
Total feed	kg	2474.4	2474.4	100.00

[a] Amount old refers to original LCI "Young dairy bull, conventional, fattening system". [b] No explicitly organic process for hay available in AGRIBALYSE, therefore unchanged. [c] Mineral feed, no explicitly organic equivalent available. [d] No explicitly organic equivalent available.

Figure 4: Changed inputs for pasture fed bulls (organic and conventional)

Flow[a]	Amount old[b]	Amount new conventional	Amount new organic
Baled hay, temporary meadow, with clover, Northwestern regions, at feeder – FR[c]	215.10	215.10	215.10
Bovine feed, CMV 5-25-5, at farm gate – FR[d]	87.53	87.53	87.53
Bovine feed, suckler feed, at farm gate – FR[e]	41.79	41.79	41.79
Grass silage, horizontal silo, permanent meadow, without clover, Auvergne, at feeder - FR	0.00	2219.84	2219.84
Maize grain dried, conventional, stored and transported, processing - FR	0.00	221.98	0.00
Dried grain maize, organic, average France, at feed plant - FR	0.00	0.00	221.98
Silage maize, conventional, national average, at feeder - FR	1121.38	0.00	0.00
Silage maize, organic, Switzerland national average, at farm gate - CH	0.00	0.00	0.00
Soft wheat grain, conventional, national average, animal feed, at farm gate, production - FR	478.70	221.98	0.00
Soft wheat grain, organic, 15% moisture, Central Region, at farm gate - FR	0.00	0.00	221.98
Soybean meal BR, crushing in Brazil, animal feed, at french port, average - FR	529.85	0.00	0.00
Soybean meal, organic, Italy national average, at feed plant - FR	0.00	0.00	0.00

[a] Only changed flows listed. [b] Amount old refers to original LCI "Young dairy bull, conventional, fattening system". [c] No explicitly organic process for hay available in AGRIBALYSE, therefore unchanged. [d] Mineral feed, no explicitly organic equivalent available. [e] No explicitly organic equivalent available.

Figure 5: Changed inputs for organic turkreys

Flow [a]	Unit	Amount old[b]	Amount new	% of total feed
Reproductive, reproductive feed, at farm gate	kg	0.69	0.00	0.00
Reproductive, reproductive feed, organic proxy, at farm gate (copy)	kg	0.00	0.69	2.72
Turkey, reproductive feed, conv prod, at farm gate	kg	0.61	0.00	0.00
Turkey, reproductive feed, organic proxy, at farm gate	kg	0.00	0.61	2.42
Turkey, turkey feed, conv prod, at farm gate	kg	24.04	0.00	0.00
Turkey, turkey feed, organic proxy, at farm gate	kg	0.00	24.04	94.86
Total feed	kg	25.35	25.35	100.00

[a] Only changed flows listed. For full list of inputs see original AGRIBALYSE v1.3 LCI "Turkey, conventional, at farm gate". [b] Amount old refers to original LCI.

Figure 6: Changed inputs for turkey's feed)

Flow old [a]	Flow new
Reproductive, reproductive feed, at farm gate	**Reproductive, reproductive feed, organic proxy, at farm gate (copy)**
Dehydrated lucerne, conventional, at feed plant - FR	Dehydrated lucerne, organic, national average, at feed plant - FR
Maize grain dried, conventional, stored and transported, processing - FR	Dried grain maize, organic, average France, at feed plant - FR
Spring pea grain stored and transported, processing - FR	Pea, organic, PaysDeLaLoire, at feed plant - FR
Rapeseed meal, conventional, animal feed, at plant - FR	Rapeseed meal, organic, Switzerland national average, at feed plant - FR
Soft wheat grain, conventional, stored and transported, processing - FR	Soft wheat grain, organic, 15% moisture, Central Region, at feed plant - FR
Soybean meal BR, crushing in Brazil, animal feed, at french port, average - FR	Soybean meal, organic, Italy national average, at feed plant - FR
Sunflower grain, conventional, dried, stored and transported, processing - FR	Sunflower, organic, average France, at feed plant - FR
Sunflower meal, with low dehulling, animal feed, at transformation plant - FR	Sunflower meal, organic, average France, at feed plant - FR
Turkey, reproductive feed, conv prod, at farm gate	**Turkey, reproductive feed, organic proxy, at farm gate**
Dehydrated lucerne, conventional, at feed plant - FR	Dehydrated lucerne, organic, national average, at feed plant - FR
Maize grain dried, conventional, stored and transported, processing - FR	Dried grain maize, organic, average France, at feed plant - FR
Spring pea grain stored and transported, processing - FR	Pea, organic, PaysDeLaLoire, at feed plant - FR
Rapeseed meal, conventional, animal feed, at plant - FR	Rapeseed meal, organic, Switzerland national average, at feed plant - FR
Soft wheat grain, conventional, stored and transported, processing - FR	Soft wheat grain, organic, 15% moisture, Central Region, at feed plant - FR
Soybean meal BR, crushing in Brazil, animal feed, at french port, average - FR	Soybean meal, organic, Italy national average, at feed plant - FR
Sunflower grain, conventional, dried, stored and transported, processing - FR	Sunflower, organic, average France, at feed plant - FR
Turkey, turkey feed, conv prod, at farm gate	**Turkey, turkey feed, organic proxy, at farm gate**
Dehydrated lucerne, conventional, at feed plant - FR	Dehydrated lucerne, organic, national average, at feed plant - FR
Maize grain dried, conventional, stored and transported, processing - FR	Dried grain maize, organic, average France, at feed plant - FR
Rapeseed meal, conventional, animal feed, at plant - FR	Rapeseed meal, organic, Switzerland national average, at feed plant - FR
Soft wheat grain, conventional, stored and transported, processing - FR	Soft wheat grain, organic, 15% moisture, Central Region, at feed plant - FR
Soybean meal BR, crushing in Brazil, animal feed, at french port, average - FR	Soybean meal, organic, Italy national average, at feed plant - FR
Spring pea grain stored and transported, processing - FR	Pea, organic, PaysDeLaLoire, at feed plant - FR
Sunflower grain, conventional, dried, stored and transported, processing - FR	Sunflower, organic, average France, at feed plant - FR

[a] Only changed flows listed. For full list of inputs see original AGRIBALYSE v1.3 LCIs "Reproductive, reproductive feed, at farm gate ", " Turkey, reproductive feed, conv prod, at farm gate", and " Turkey, turkey feed, conv prod, at farm gate". [b] Amount old refers to original LCIs.

Figure 7: Handling of co-products by the system expansion approach

Livestock process – product (system expansion)	Added processes – co-product	Ratio[a] product : co-product
"Cow milk, conventional, highland milk system, grass fed" - milk	"Cull cow, conventional, highland milk system, grass fed" - beef	1 : 0.0125
	"Young dairy bull, proxy pasture system conventional, fattening system, at farm gate" - beef	1 : 0.0289
"Cow milk, conventional, lowland milk system, silage maize more than 30 %" - milk	"Cull cow, conventional, lowland milk system, silage maize more than 30 %" - beef	1 : 0.0117
	"Young dairy bull, conventional, fattening system" - beef	1 : 0.0120
"Cow milk, organic, lowland milk system, silage maize 5 to 10 % [-pasture]" - milk	"Cull cow, organic, lowland milk system, silage maize 5 to 10 %" - beef	1 : 0.0130
	"Young dairy bull, proxy pasture system, organic proxy, fattening system, at farm gate" - beef	1 : 0.0211
"Cow milk, organic, lowland milk system, silage maize 5 to 10 % [-arable]" – milk	"Cull cow, organic, lowland milk system, silage maize 5 to 10 %" - beef	1 : 0.0130
	"Young dairy bull, organic proxy, fattening system" – beef	1 : 0.0211
"Pig, conventional, on-farm feed supply" - pork	"Cull sow, conventional, on-farm feed supply" - pork	1 : 0.0349
"Pig, organic" - pork	"Cull sow, organic" - pork	1 : 0.0503
"Egg, conventional, indoor system, non-cage" - egg	"Cull hen, conventional, indoor system, non-cage" - poultry	1 : 0.0652
"Egg, organic" - egg	"Cull hen, organic" - poultry	1 : 0.0670

[a] Ratio of kg edible weight produced.

Figure 8: LCI selection for crops

Vegetal food crops	AGRIBALYSE LCI Conventional	AGRIBALYSE LCI Organic
carrot	Carrot conventional national average at farm gate	Carrot organic Lower Normandy at farm gate
lettuce	*no LCI in AGRIBALYSE - as proxy: same as carrot conventional*	*no LCI in AGRIBALYSE - as proxy: same as carrot organic*
potato	Ware potato conventional variety mix national average at farm gate	*no LCI in AGRIBALYSE - as proxy: same as potato conventional*
rapeseed[a]	Rapeseed conventional 9% moisture national average at farm gate	*no LCI in AGRIBALYSE - as proxy: same as rapeseed conventional*
rye	*no LCI in AGRIBALYSE - as proxy: same as wheat conv*	*no LCI in AGRIBALYSE - as proxy: same as wheat organic*
spring pea	Spring pea conventional 15% moisture at farm gate	*no LCI in AGRIBALYSE - as proxy: same as spring pea conventional*
sugar beet	Sugar beet roots conventional national average at farm gate	*no LCI in AGRIBALYSE - as proxy: same as sugar beet con.*
sunflower[a]	Sunflower conventional 9% moisture national average at farm gate	average (50:50) of "Sunflower grain organic PaysDeLaLoire at farm gate" + "Sunflower grain organic Gers at farm gate"
tomato	Tomato conventional greenhouse production national average at greenhouse	Tomato organic greenhouse production national average at greenhouse
wheat	Soft wheat grain conventional national average at farm gate	average (50:50) of "Soft wheat grain organic (model type) after Alfalfa Central Region at farm gate" + "Soft wheat grain organic (model type) after fava beans Central Region at farm gate"

1.3 Land classes

1.3.1 Agricultural Requirements of Crops

The classification of land suitability for certain crops was based on the criterions and thresholds used by Kaule et al. (2011): maximum slope, maximum stone content, mini-mum soil depth, precluding soil type, minimum mean annual temperature, minimum mean annual precipitation and maximum ground water table. As their research is about energy crops, values for crops used only for food were missing. Minimum soil depth, minimum mean annual temperature and minimum mean annual precipitation was taken from FAO's EcoCrop Database. Values for maximum stone content and maximum ground water table used by Kaule et al. (2011) are consistent within the groups legumes, other above ground crops and below ground crops. They were therefore assumed to be the same for the correspondent food crop here (i.e. carrots were assumed to tolerate a maximum stone content of 33%, because Kaule et al. (2011) use this value for all below ground crops). The precluding soil type used by Kaule et al. (2011) was also consistent for legumes but not for other crops. Therefore precluding soil type for crops other than legumes values were taken from VELA (2014). No publicly available source for maximum slope could be found. Also the resolution of publicly available geodata for slope respec-tively elevation (which can be converted to slope) was not sufficient to accurately reflect the flat valleys and sudden steep rises of Eastern Black Forrest and Kaiserstuhl. Therefore this criterion was dropped from the analysis.

1.3.2 Geodata Sources

Only land that is currently used as cropland was included in this analysis. As the official data from the topographical cartographic information system ATKIS was not publicly available in BW, Corine Landcover Data downloaded from Bundesamt für Kartografie und Geodäsie (BKG) was used. Its clc-code "211" identifies 970,000 ha of "non-irrigated arable land" in BW BKG (2017). Climate Data was taken from the ftp-server (ftp://ftp-cdc.dwd.de/pub/CDC/) of the Deutsche Wetterdienst (DWD) as raster files of multi-annual mean temperature DWD (2016) and multi-annual mean precipitation DWD (2017), both covering the years 1981 -2010. Soil data was taken from the product center of the BGR. Soil depth is available as raster file based on the BUEK1000 (soil overview map with scale 1:1,000,000) BGR (2015). Raster cells covering cities have null values. That leads to data voids for soil depth for some fields adjacent of cities. These fields were excluded from the analysis. All other soil data was taken from BUEK200 (soil overview map with scale 1:200,000), which is availa-ble as single shapefiles of ca. 100 km by 100 km extension BGR (2016) and comple-mented by an accdb database file BGR (2010). BGR will finish the BUEK200 project in 2019, at the time of the analysis some parts of BW were not yet available. These areas include 120,000 ha of agricultural fields from the CORINE landcover dataset and are also not considered in the analysis. This is compensated by not including fruits in the food basket. After the subtractions mentioned above 810,000 ha fields remain in the analysis which is only 10,000 ha less than the official number of the Statistische Landesamt Baden-Württemberg SLA-BW (2017).

1.3.3 Geodata handling

Only open-source software was used to work with the data. pgAdmin III was used to create a PostgreSQL database with PostGIS extension to store the data. The OSGeo4W shell was used to import shapefiles and raster files into the database. All raster files were vectorized and all data sets covering more than BW were clipped to BW boundaries using the VG250 dataset of the Bundesamt für Kartographie und Geodäsie (BKG, 2016). If datasets gave absolute values they were classified according to the class boundaries derived from the thresholds given by Kaule et al. (2011). If they already included classi-fied data and class boundaries did not coincide with Kaule et al.'s thresholds, suitability was determined by whether or not more than half of the values in this class are suitable for the crop in question. After classification data sets were basically combined via st_intersection-sql-prompts. Due to some drawbacks of the postgres sql-query-tool re-garding error handling and progress reporting, the sql-prompts were embedded into a python script that iterated over the geo-objects in the cropland table and executed the intersection prompt for each object separately. This made it possible to commit the result after each execution of the intersection prompt and prevented data loss due to roll backs after errors. The python package psycopg2 was used to access the postgres data-base via python.

1.3.4 Resulting Landclasses

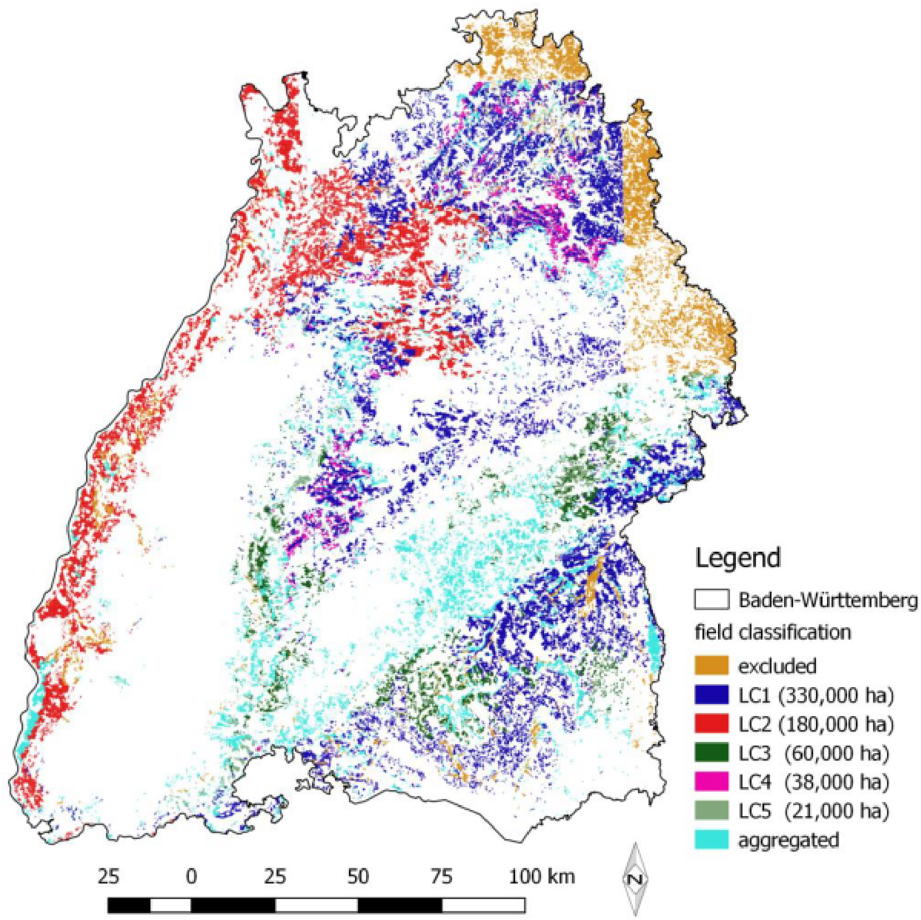

Figure 9: Agricultural Landclasses for BW. LC 6 to LC 137 were aggregated to maintain clarity

Table 5: shows which crop can be grown in which land class. The letter T stands for true and indicates that the crop can be grown in the respective land class (row numbers). Abbreviations are as follows: car. = carrots; let. = lettuce; pot. = potatoes; rap. = rapeseed; sug. = sugarbeet; sun. = sunflower; tom. = tomatoes; bar. = barley; m.gr. = maizegrain, m.si = maizesilage; alf. = alfalfa; tric. = tricitale grain

	car.	let.	pot.	rap.	rye	pea	sug.	sun.	tom.	wheat	bar.	m.gr.	m.si.	alf.	soy	tric.
1	T	T	T	T	T	T	T	T	T	T	T	T	T	T	-	T
2	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T
3	T	T	T	T	T	T	T	-	T	T	T	T	T	T	-	T
4	-	T	T	T	T	T	T	T	T	T	T	T	T	T	-	T
5	-	T	-	-	T	T	-	-	T	T	-	T	T	T	-	T
6	-	-	-	-	T	T	-	-	T	T	-	T	T	T	-	T
7	-	T	-	-	T	T	-	-	T	T	-	-	T	T	-	T

8	T	T	T	T	T	T	-	-	T	T	T	-	T	T	-	T
9	T	-	T	T	T	T	T	T	T	T	T	T	T	T	-	T
10	-	T	T	-	T	T	T	-	T	T	T	T	T	T	-	T
11	T	T	T	-	T	T	T	-	T	T	T	T	T	T	-	T
12	-	-	-	-	T	-	-	-	-	T	-	T	T	T	-	T
13	-	T	-	-	T	T	-	-	T	T	T	T	T	T	-	T
14	-	T	T	T	T	T	T	-	T	T	T	T	T	T	-	T
15	-	T	T	-	T	T	T	-	T	T	T	T	T	T	T	T
16	-	-	T	T	T	-	T	T	-	T	-	T	T	T	-	T
17	T	-	T	T	T	T	T	T	T	T	T	T	T	T	T	T
18	-	-	-	-	T	-	-	-	-	T	-	-	T	T	-	T
19	-	-	-	-	T	T	-	-	T	T	-	-	T	T	-	T
20	-	-	T	T	T	-	T	T	-	T	T	T	T	T	-	T
21	-	-	-	T	T	T	-	T	T	T	T	T	T	T	-	T
22	-	-	-	T	T	-	-	T	-	T	T	T	T	T	-	T
23	-	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T
24	-	T	-	T	T	T	-	-	T	T	T	T	T	T	-	T
25	-	-	-	T	T	-	-	T	-	T	-	T	T	T	-	T
26	-	T	-	T	T	T	-	-	T	T	T	-	T	T	-	T
27	-	T	-	T	T	T	-	T	T	T	T	T	T	T	-	T
28	T	-	-	T	T	T	-	T	T	T	T	T	T	T	-	T
29	T	T	-	-	-	-	-	T	T	-	-	-	-	-	-	-
30	T	-	T	T	T	T	-	T	T	T	T	T	T	T	-	T
31	-	T	T	T	T	T	-	-	T	T	T	-	T	T	-	T
32	-	T	T	T	T	T	-	T	T	T	T	T	T	T	-	T
33	T	T	T	-	T	T	T	-	T	T	T	T	T	T	T	T
34	-	T	-	-	T	T	-	-	-	T	-	-	T	T	-	T
35	-	-	-	-	T	T	-	-	T	T	T	T	T	T	-	T
36	-	-	-	-	T	-	-	-	-	T	T	T	T	T	-	T
37	T	-	-	T	T	T	-	T	T	T	T	T	T	T	T	T
38	-	-	T	T	T	T	T	-	T	T	T	T	T	T	-	T
39	-	-	T	T	T	T	T	T	T	T	T	T	T	T	-	T
40	T	T	-	T	T	T	-	T	T	T	T	T	T	T	-	T
41	T	-	T	T	T	T	T	-	T	T	T	T	T	T	-	T
42	T	-	T	T	T	T	-	T	T	T	-	T	T	T	T	T
43	T	T	T	-	T	T	T	T	T	T	T	T	T	T	T	T
44	T	-	T	-	T	T	T	-	T	T	T	T	T	T	-	T
45	T	T	T	T	T	T	-	-	-	T	T	-	T	T	-	T
46	T	-	-	T	T	T	-	-	T	T	T	T	T	T	-	T
47	-	-	T	T	T	-	T	-	-	T	-	T	T	T	-	T
48	T	-	T	T	T	T	-	T	T	T	T	T	T	T	T	T
49	-	-	-	-	-	-	-	-	-	-	-	-	-	T	-	-
50	-	-	-	T	T	-	T	T	-	T	T	T	T	T	-	T
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57	-	T	-	-	T	T	-	-	T	T	T	T	T	T	T	T
58	-	T	-	-	T	T	-	-	T	T	T	-	T	T	-	T
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61	T	T	T	T	T	T	-	T	T	T	T	T	T	T	-	T
62	-	-	T	-	T	-	T	-	-	T	T	T	T	T	-	T
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67	T	T	-	T	T	T	-	-	T	T	T	T	T	T	-	T
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72	T	-	T	-	T	T	T	-	T	T	T	T	T	T	T	T
73	-	T	T	T	T	T	-	-	T	T	T	T	T	T	-	T
74	-	-	T	T	T	T	-	-	T	T	T	-	T	T	-	T
75	-	T	T	T	T	T	-	-	-	T	T	-	T	T	-	T
76	T	T	-	-	T	T	-	-	T	T	T	T	T	T	-	T
77	-	-	-	T	T	-	-	-	-	T	-	T	T	T	-	T
78	-	-	-	-	T	T	-	-	T	T	-	T	T	T	T	T
79	T	T	T	-	T	T	-	-	T	T	T	T	T	T	-	T
80	-	-	-	-	T	-	-	-	-	T	T	-	T	T	-	T
81	T	T	T	T	T	T	-	T	T	-	-	T	T	T	-	T
82	-	T	-	T	T	T	T	-	T	T	T	T	T	T	-	T
83	-	-	-	T	T	T	-	T	T	T	T	T	T	T	T	T
84	T	-	T	T	T	T	-	-	T	T	T	-	T	T	-	T
85	T	T	T	T	T	T	-	-	T	T	T	T	T	T	-	T
86	T	T	-	-	T	T	-	-	T	T	-	T	T	T	-	T
87	-	T	T	T	T	T	-	T	T	-	-	T	T	T	T	T
88	-	T	T	-	T	T	-	-	T	-	-	T	T	T	-	T
89	-	-	-	-	T	T	-	-	T	T	T	T	T	T	T	T
90	-	T	-	T	T	T	T	T	T	T	T	T	T	T	-	T
91	-	-	T	-	T	-	T	-	-	T	-	T	T	T	-	T
92	-	T	T	T	T	T	-	-	T	-	-	T	T	T	-	T
93	-	T	-	T	T	T	-	-	-	T	T	-	T	T	-	T
94	T	T	T	-	T	T	-	-	-	T	T	-	T	T	-	T
95	-	T	T	-	T	T	-	-	T	T	T	T	T	T	T	T
96	T	T	-	T	T	T	-	-	T	T	T	-	T	T	-	T
97	-	-	-	T	T	-	T	T	-	T	-	T	T	T	-	T
98	-	T	-	T	T	T	-	T	T	T	T	T	T	T	T	T
99	-	-	T	T	T	-	-	T	-	T	T	T	T	T	-	T
100	-	T	T	-	T	T	-	-	-	T	T	-	T	T	-	T
101	-	-	T	T	T	T	T	T	T	T	T	T	T	T	T	T
102	T	-	-	-	T	T	-	-	T	T	T	T	T	T	-	T
103	-	T	T	-	T	T	-	-	T	-	-	T	T	T	T	T
104	-	-	T	T	T	-	-	-	-	T	T	-	T	T	-	T
105	-	-	T	-	T	T	-	-	T	T	T	-	T	T	-	T
106	T	-	T	-	T	T	-	-	T	T	T	T	T	T	T	T
107	-	-	-	T	T	T	-	-	T	T	T	T	T	T	-	T
108	-	-	T	T	T	-	-	-	-	T	T	T	T	T	-	T
109	T	-	T	-	T	T	-	-	T	T	T	-	T	T	-	T
110	-	-	-	T	T	-	T	-	-	T	-	T	T	T	-	T
111	-	-	T	-	T	-	-	-	-	T	T	T	T	T	-	T

112	T	T	-	T	T	T	-	-	-	T	T	-	T	T	-	T
113	-	T	-	-	T	T	T	-	T	T	T	T	T	T	-	T
114	-	-	T	T	T	-	-	-	-	T	-	T	T	T	-	T
115	-	-	T	T	T	-	-	T	-	T	-	T	T	T	-	T
116	-	T	-	T	T	T	-	T	T	-	-	T	T	T	-	T
117	-	-	-	T	T	-	-	T	-	-	-	T	T	T	-	T
118	-	-	T	T	T	-	-	T	-	-	-	T	T	T	-	T
119	-	-	-	T	T	-	-	-	-	-	-	-	T	T	-	T
120	T	T	-	-	T	T	-	-	T	T	T	-	T	T	-	T
121	-	-	T	-	T	T	T	-	T	T	T	T	T	T	T	T
122	-	-	-	-	T	T	-	-	T	T	T	-	T	T	-	T
123	-	T	T	T	T	T	-	-	T	-	-	-	T	T	-	T
124	-	-	T	-	T	-	-	-	-	T	-	-	T	T	-	T
125	T	T	T	T	T	T	-	T	T	T	T	T	T	T	T	T
126	-	-	T	-	T	-	-	-	-	T	T	-	T	T	-	T
127	-	T	-	-	T	T	-	-	-	T	T	-	T	T	-	T
128	-	-	T	-	T	-	-	-	-	T	-	T	T	T	-	T
129	-	T	-	T	T	T	-	-	T	-	-	T	T	T	-	T
130	T	T	T	-	T	T	-	-	T	-	-	T	T	T	-	T
131	-	T	-	T	T	T	-	-	T	-	-	-	T	T	-	T
132	T	T	-	-	T	T	-	-	-	T	T	-	T	T	-	T
133	-	-	-	-	T	-	-	-	-	-	-	T	T	T	-	T
134	-	T	T	T	T	T	-	-	-	-	-	-	T	T	-	T
135	-	T	-	-	T	T	-	-	T	-	-	T	T	T	-	T
136	T	-	-	-	T	T	-	-	T	T	T	T	T	T	T	T
137	-	-	-	T	T	-	-	-	-	-	-	T	T	T	-	T

1.4 Agricultural production Model and LSS calculation

The agricultural production model mentioned in the paper actually consist of two sub-models. One that allocates the agricultural land (agricultural allocation model) and another one that calculates to which degree the demand can be met (demand fulfillment model). These two give the information necessary to calculate LSS values. Crop rotation and the handling of co-products are incorporated in the two models as follows

1.4.1 Co-products

In the model, co-products are considered by a system expansion approach. This means the production of a certain amount of a main product automatically produces a certain amount of a co-product. The co-factors, representing the ratio of main- and co-product, were taken from the AGRIBALYSE v1.3 database. In this model, the main products milk and eggs were coupled with their co-products beef and broiler.

1.4.2 Crop rotation

In practice, food crops are not grown on the same land all the time but follow a certain crop rotation to diminish nutrition leaching from the soil. In the model, this fact is not included geographically but in a more simple form: for each land class, only a certain proportion can be used to grow a single crop. These crop specific proportions (crop rotation factors) were taken from VELA(2014) and KTBL (2009). If, for example the area of a land class would be 50 ha and the crop rotation factor for a given crop was 20 percent, then only 10 ha would be available for growing that crop within that land class.

1.4.3 Agricultural allocation model (AAM)

We developed a model (AAM) to simulate how cropping areas might be allocated within BW. Following inputs are used:

- A vector of product quantities for 17 products (each in organic and conventional) [kt].
- A vector containing the area of arable land for each land class (initial area available; IAA). Each element of the vector represents the area of one land class.
- The area of available pasture as natural number [ha] .
- A list containing all possible land classes where a crop can be grown for each crop (LC). Each element of the list is a vector representing a certain crop. Each element of the vector is the number of a land class where the crop can be grown.
- A vector containing agricultural land occupation values (ALO) for each crop.
- A vector containing crop rotation factors (cr) for each crop.
- A matrix F that contains fodder consumption for each animal product (amount of feed crops needed to produce one unit of an animal based food product).

In the model animal products are represented in form of fodder-crops that are consumed by the animals. Therefore quantities for animal products ($\vec{Q_a}$) need to be transformed into fodder quantities ($\vec{Q_f}$). This is done by multiplying $\vec{Q_a}$ with the fodder consumption matrix F. Combined with the vegetal food-crops' quantities ($\vec{Q_v}$), both form the indirect product quantity. Because some food-crops are also fodder-crops, their amount is combined so they count as one when it comes to crop rotation constraints.

$$\vec{Q} = \begin{pmatrix} \vec{Q_v} \\ \vec{Q_a} \end{pmatrix}$$

$$\vec{Q_f} = \vec{Q_a} F$$

$$I\vec{Q} = \begin{pmatrix} \vec{Q_v} \\ \vec{Q_f} \end{pmatrix}$$

The model's core consists of an outer- and an inner for-loop (shown in Figure 10).
The outer for-loop iterates through all indirect product quantities (food- and fodder-crops) and calculates the area needed (need) to cultivate these crops by multiplying the quantity with a corresponding ALO-value. In which succession the crops are cultivated is based on their maximum demand fulfillment rate (calculated by Bitterich, 2018) in ascending order. These maximum demand fulfillment rates (MDFR) represent the share to which a certain product would meet it's demand if only this product would be grown in BW (I.e. all of BW's agricutural land can be used for this one crop). By cultivating them according to their MDFR-value, crops that are either "picky" regarding land classes (e.g. soy) or have a great demand, which leads to crop rotation restrictions (e.g. sunflower), are taken care of first. For every product, first it's organic quantity is cultivated, then it's conventional. That organic was chosen first has no deeper meaning but the order needs to be coherent for crop rotation calculations.
The inner for-loop iterates through all land classes where the current product can be grown and uses up the area available within the respective land class for cultivation. The iteration runs from smallest land class (regarding area) to biggest, because in smaller land classes fewer crop species can be grown. By using up the small land classes first, it is assured that also these "picky", areas are used. Starting both sequences (crops and land classes) with the "picky" ones is important for an optimal use of agricultural land, which will automatically result in optimal LSS-values (due to it's area based nature).
For each product (p) and land class (c) the area which is actually available under crop rotation constraints (AACR) is determined. Because each product has different crop rotation factors for organic and conventional

production they need to be calculated seperately. Because the organic product is always cultivated first, it's area available under crop rotation constraints is calculated as follows:

$$AACR(p_o, c) = min(IAA(c) * cr(p_o), AA(c))$$

With AACR being the area available under crop rotation constraints, IAA the initial area available (before anything was cropped), cr the crop rotation factor and AA the area that is currently available. Because the minimum is taken, it is assured that maximally the area, which is allowed under crop rotation constraints, will be used. For the conventional product an additional variable $AO(p_o)$ is added. It stands for the area that is occupied by the organic product. In this sense, occupied is not the area used for cultivating the organic product $AU(p_o)$ but also the area that "is reserved" for crop rotation, which is $AU(p_o)$ divided by the crop rotation factor $cr(p_o)$. For the conventional product this gives following formular:

$$AO(p_o, c) = AU(p_o, c)/cr(p_o)$$
$$AACR(p_c, c) = min((IAA(c) - AO(p_o, c)) * cr(p_c), AA(c))$$

Now, this area is used to cultivate the current crop. I. e. the area available under crop rotation constraints is subtracted from the need of the current product, and from the actual area available within the current land class. If the resulting need is bigger than zero (still needs to be satisfied) the inner for-loop continues and the next bigger land class is used for cultivating the current crop. Once the need is smaller than zero, it's absolute value is "added back" to the area available within the current land class and the need is set to zero. In that case, the inner for-loop breaks because the need could already be satisfied. Then the outer for-loop continues with the next product.

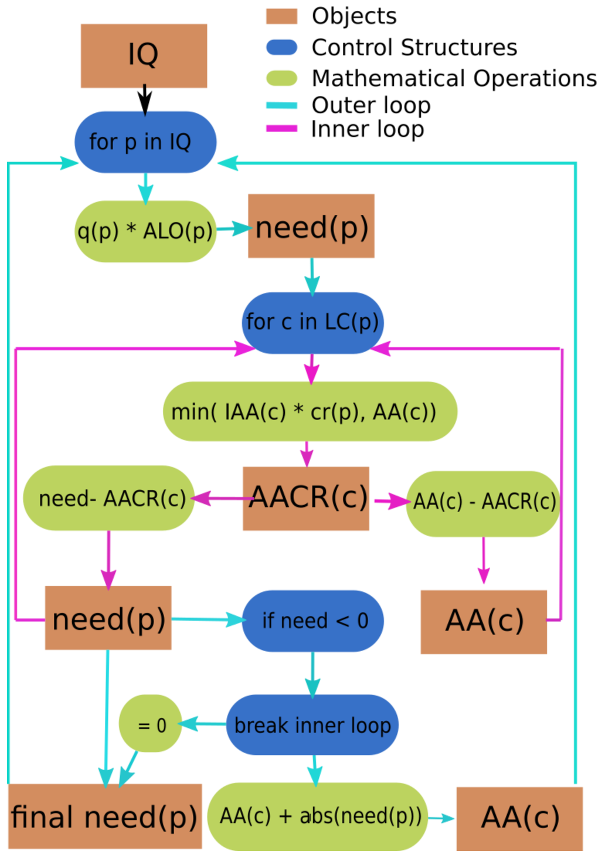

Figure 10: Shows a flowchart of the AAM's structure. It's names are coded as follows: **IQ** - Indirect quantity (all crops); **q(p)** - quantity of product p; **ALO(p)** - agricultural land occupation for product p; **need(p)** - area required to grow a quantity q of p; **LC(p)** - all land classes where p can be grown; **IAA(c)** - inital area available in land class c; **cr(p)** - crop rotation factor for product p; **AA(c)** - current area available in land class c; **AACR(c)** - current area available in land class c under crop rotation constraints; **final need(p)** - remaining area required to grow p (if zero, the area was sufficient. If not, it's absolute value is the area that is lacking)

If the current product is pasture, there is no need for an inner for-loop as it doesn't have several land classes. Crop rotation factors are irrelevant as well.
At the end of each iteration of the outer for-loop, the remaining need after iterating through all land classes is stored in a vector (final need). If any element of this vector is greater than zero, it means the need for area could not be satisfied, I. e. production with current product quantities would exceed the areal limitations by that area.

1.4.4 Demand fulfillment model (DFM)

We developed a model (DFM) to simulate to which degree the food demand for a given population and product-quantities would be satisfied. Following inputs are used:

- A vector of product quantities for 17 products (each in organic and conventional) [kt].
- Per capita food demand for 14 product categories. This demand is different for the scenarios base, vegetarian and vegan .
- Population size as natural number.

- Co-factors that quantify the production of co-products per amount of product.

First, the total food demand is calculated by multiplying the population size with the per capita food demand. Then, a for-loop iterates through all products (direct) and calculates how much food of a certain category is produced, because demand values only exist for food categories, not for products. In the cases where food product and category are the same, that is simply the product's quantity. In the case of oil, poultry and milk, they need to be added up according to their category (see Table **??**) . Also co-products are considered here, I.e. if a certain product has co-products, it's quantity multiplied by the co-factor is added to the co products' category. Finally, the amount of food produced for each category is divided by it's total demand, giving category specific demand fulfillment rates.

1.4.5 calculation

LSS is defined as the area used for current food production divided by the area necessary to produce such an amount of food, that the demand would be met. The LSS function needs to calculate exactly that with 32 product quantities as input. The first step to do this is calculate demand fulfillment rates for each product category (with DFM) with the given quantities. Then, the area needed by each product category $N(k)$ is calculated (with an alteration of AAM). With these values, the area missing for a product category can be calculated. It is the share of missing demand (100 - DFR) divided by the demand fulfillment rate, multiplied with the area needed for this product category with current quantities. For example let's assume a category's demand fulfillment rate is 60% and it needs 20 ha arable land. Then $\frac{40}{60}$ multiplied with 20 ha yields 13.3 ha as the area which is needed to crop the missing 40%. Because the missing area was calculated by multiplying the area that is currently needed for a certain category, it's composition of products is the same (mirrored estimation). This means that if e.g. oil production is currently made up of 30% sunflower and 70% rapeseed, then the proportion will be the same for the missing area. At this point, it is important to take co-products into account. Because the demand for beef is fully satisfied by milk production, beef is not produced separately and can therefore be neglected. The only co-product left is poultry gained by producing eggs. Poultry's share of missing demand includes the amount gained by producing the current quantity of eggs, which would lead to false assumptions in calculating the area still needed to meet the demand. The solution here is, to diminish the demand for poultry by the amount of poultry that is produced if the demand for eggs would be met. With this fixed demand a new demand fulfillment rate and the area missing for poultry can be calculated (same procedure as above).
Dividing the area needed to produce the current quantities by the sum of the area needed if the demand would be met for each product category (i.e. if total demand would be met under same conditions as the current situation), gives an area based level of self-sufficiency (LSS). To ensure that the area is not exceeded, the LSS-value is divided by a penalty factor p_a, which is defined as the sum of the AAM's result (total area by which area available is exceeded). In case p_a is lower than 1, it is set to 1. By that, very small exceedances and staying within areal limitations will have no penalty (divided by 1). In mathematical terms the function can be formulated as follows:

$$LSS = \frac{\sum_{k=1}^{14} N(k)}{\sum_{k=1}^{14} N(k) + \sum_{k=1}^{14} (N(k) * \frac{100-DFR(k)}{DFR(k)})}$$

with $N(k)$ being the area needed by category k. DFR refers to demand fulfillment rate. It is worth mentioning that it is not possible to calculate LSS-values if products of a certain category are not produced at all. In that case the demand fulfillment rate of this category would be zero. In the formular the share of missing demand is divided by the DFR. Hence, it being zero would violate a fundamental mathematical rule. Hence, it is assured that instead of zero, very small values serve as lower boundaries for each product quantity.

1.5 Model parameters

1.5.1 ALO-values and Crop rotation factors

Table 6: shows ALO-values und crop rotation factors for all crops. The subscribt o and c stand for organic and conventional production. ALO values were taken from the AGRIBALYSE database (ADEME, 2017),crop rotation factors were derived from VELA (2014) and Kolbe (2008)

	crop	ALO [ha*yr/kt]	crop rotation factor [-]
1	carrots_o	29	0.2
2	carrots_c	20.3	0.2
3	lettuce_o	36.7	0.23
4	lettuce_c	27.6	0.23
5	potato_o	40	0.23
6	potato_c	25.4	0.29
7	rapeseed_o	500	0.23
8	rapeseed_c	271	0.25
9	rye_o	250	0.42
10	rye_c	170	0.58
11	pea_o	250	0.15
12	pea_c	154	0.18
13	sugarbeet_o	20	0.2
14	sugarbeet_c	13	0.25
15	sunflower_o	333	0.14
16	sunflower_c	333	0.2
17	tomatoes_o	9.4	0.23
18	tomatoes_c	7.1	0.23
19	wheat_o	250	0.33
20	wheat_c	136	0.58
21	pasture_c	34	1
22	alfalfa_c	103	0.3
23	barley_c	151	0.42
24	maizegrain_c	94	0.5
25	maizesilage_c	74	0.5
26	soybean_c	246	0.25
27	pasture_o	34	1
28	alfalfa_o	103	0.2
29	barley_o	250	0.29
30	maizegrain_o	192	0.42
31	maizesilage_o	95	0.42
32	soybean_o	385	0.23
33	tricitalegrain_o	250	0.29

1.5.2 Feedstuff demand

Table 7: Shows feedstuff demand (in kt/kt) for each animal based product. The subscribt o and c stand for organic and conventional production. The subscribts a and p for milk stand for arab fed and pasture fed. Values were taken from the AGRIBALYSE database (ADEME, 2017)

	alo_feedstuff	broiler_o	broiler_c	egg_o	egg_c	pig_o	pig_c	turkey_o	turkey_c	milk_o_p	milk_c_p	milk_o_a	milk_c_a
1	pasture_c	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	10.07	0.00	2.60
2	alfalfa_c	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	barley_c	0.00	0.00	0.00	0.00	0.00	0.77	0.00	0.00	0.00	0.00	0.00	0.00
4	maizegrain_c	0.12	1.93	0.46	1.37	0.00	0.96	0.00	0.94	0.00	0.03	0.00	0.00
5	maizesilage_c	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.49
6	rapeseed_c	0.00	0.11	0.00	0.03	0.00	0.49	0.00	0.00	0.00	0.08	0.00	0.00
7	wheat_c	0.36	0.97	0.29	0.89	0.00	2.48	0.00	1.64	0.00	0.21	0.00	0.12
8	soybean_c	0.00	0.62	0.08	0.49	0.00	0.38	0.15	1.20	0.00	0.00	0.00	0.10
9	pea_c	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.18	0.00	0.00	0.00	0.00
10	sunflower_c	0.00	0.00	0.00	0.03	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.00
11	sugarbeet_c	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
12	pasture_o	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	7.75	0.00	6.49	0.00
13	alfalfa_o	0.00	0.00	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
14	barley_o	0.00	0.00	0.00	0.00	1.59	0.00	0.00	0.00	0.00	0.00	0.00	0.00
15	pea_o	0.15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.00	0.06	0.00
16	maizegrain_o	2.29	0.00	0.68	0.00	0.00	0.00	0.80	0.00	0.02	0.00	0.00	0.00
17	maizesilage_o	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.18	0.00	0.27	0.00
18	pea_o	0.15	0.00	0.08	0.00	1.48	0.00	0.18	0.00	0.04	0.00	0.04	0.00
19	rapeseed_o	0.00	0.00	0.03	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	wheat_o	0.59	0.00	0.44	0.00	1.01	0.00	1.64	0.00	0.02	0.00	0.04	0.00
21	soybean_o	1.25	0.00	0.43	0.00	0.83	0.00	1.49	0.00	0.04	0.00	0.09	0.00
22	barley_o	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
23	sunflower_o	0.31	0.00	0.31	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
24	tricitalegrain_o	0.47	0.00	0.16	0.00	1.42	0.00	0.00	0.00	0.07	0.00	0.07	0.00

1.5.3 Co-factors

Table 8: shows co-factors for milk production. For every kt of milk x kt of beef is produced. The subscribts a and p for milk stand for arab fed and pasture fed. The subscribt o and c stand for organic and conventional production. Values taken from the AGRIBALYSE database (ADEME, 2017)

	milk_o_p	milk_c_p	milk_o_a	milk_c_a
beef	0.03	0.04	0.03	0.02

Table 9: shows co-factors for egg production. For every kt of eggs x kt of poultry is produced. The subscribt o and c stand for organic and conventional production. Values taken from the AGRIBALYSE database (ADEME, 2017)

	egg_o	egg_c
poultry	0.07	0.07

1.5.4 Maximum demand fulfillment rates

Table 10: shows maximal demand fulfillment rates for all products with values below 100%.

Crop	Conv.	Org.
Wheat	99%	51%
Rapeseed	43%	35%
Sunflower	39%	25%
Soy	44%	13%
Pasture	38%	49%
Pea	7500%	38%

1.6 Optimization

1.6.1 Mechanistic approach

For the EA to find the best solution, reasonable boundaries and possible solutions as starting population need to be provided. In order to estimate these parameters, a mechanistic approach, which tries to fulfill the demand without exceeding the area, was developed. The underlying concept of this approach is, to gradually increase product quantities in a way, that the demand fulfillment rate of each category increases by one percent. If increasing the quantity of a certain product would lead to an exceedance of the area available (with AAM), or the demand of it's corresponding product category is met (with DFM), the quantity of this product cannot further increase. If no product can increase any further, the program stops. Overproduction or exceeding the area is not possible because both cases are stop criteria for increasing a product.
The mechanistic approach has two configurations. One with all products being produced organic and one with everything being produced conventional. In the MO these two configurations were used to same parts for the starting population to ensure a big variety. The parameters that influence which products to choose for a category (sunflower or rapeseed for oil; broiler or turkey for poultry; arab fed or pasture fed milk) are determined randomly. Additionally, a random element ensures, that in some cases milk production is increased to its maximum before all other products so that the pasture is fully used.

1.6.2 Starting parameters

For the EA to find optimal solutions, it is necessary to provide starting populations as well as upper and lower boundaries for the input parameters. Lower boundaries are set to 1 kg (= 0.000001 kt) for all product quantities. It is not zero because then the LSS calculation might not work (as described above). If the semi mechanistic approach is run with limitless arable land and pasture, the resulting quantities of a category can be used to set upper boundaries for the respective products (the semi mechanistic approach does not allow overproduction). This means, e.g. the upper boundary for both, sunflower and rapeseed is the sum of their quantities given by the limitless semi mechanistic approach, which provides freedom which crop to choose for oil production. Due to higher ALO-values organic vegetables can be excluded from LSS optimization. This is done by setting upper boundaries for organic vegetable products to 100 kg (= 0.0001 kt), because upper boundaries need to be higher than lower boundaries for the EA to work.

1.7 Retrieving desirabilities

In order to judge the performance of a point regarding an objective, it's value is related to real life values. For that, the range of an objective is divided into sub-ranges. Each of these sub ranges has an upper threshold. If a value is below that threshold it is classified with the corresponding desirability class. The only exception is the undesirable threshold which acts as upper threshold for the undesirable class and as lower threshold for the highly undesirable class. For the impact categories climate change, marine eutrophication and terrestrial acidification, actual emissions were used to determine undesirable threshold values because for these impact categories the German government agrees that actual emissions are too high. It also defined goals to reduce emissions. These goals were used to determine highly desirable threshold values. I.e. impacts below that value are classified as highly desirable. The threshold values for the intermediate classes "desirable" and "tolerable" are determined linearly over the range between highly desirable and undesirable. For terrestiral ecotoxicity desirabilities could not be related to real life data and were therefore determined linearly over the range of impact values. The desirability for LSS-values was set to a reasonable range retrieved by previous results.

1. Climate change
   According to the climate protection plan of the German federal environment agency, 2014 Germany emitted 72 mio tons of CO2-quivalents in the agricultural sector and plans to reduce it to 58 - 61 million tons of CO2 equivalents until 2030 (BMU). For climate change it is convenient that the goals are defined in the same unit as the impact category of the LCA analysis and no transformation needs to be done. Because the emission values refer to German agriculture they need to be multiplied with the share BW's agricultural land has on Germany's agricultural land (from Umweltbundesamt_1, 2018) to retrieve highly desirable and undesirable threshold values respectively.
2. Eutrophication
   In the recipe (which was used for LCIA) method, nitrogen emissions to the environment are treated as marine eutrophication as it is the limiting nutrient in oceans (Goedkoop et al., 2009). The Ministry for Environment, Climate and Eenergy Baden-Wuerttemberg states that BW's agriculture has average nitrate emissions of 22 kg per hectar and year. This results in nitrate deposition of 15 kg per hectar and year (MECE BW, 2018). For the definition of desirability for nitrogen emissions the concept of critical loads is helpful. According to the german federal environment agency critical loads are defined as "a quantitative estimate of an exposure to one or more pollutants below which significant harmful effects on specified sensitive elements of the environment do not occur according to present knowledge"(Schlutow, 2017). Because the most sensitive ecosystems in BW have critical load values of 3 - 5 kg per hectar and year, this range multiplied with the emission-deposition ratio of 1.47 yields the emission values that are highly desirable (4.41 - 7.35 kg per hectar and year). The current emission value of 22 kg per hectar and year is set as undesirable.

3. Acidification

   According to the recipe method, acidification only occurs due to SO_2 -,NH_3 - and NO_x emissions (Goedkoop et al., 2009). The german federal environmental office provide detailed, sector-specific emission data for these three polutants (Umweltbundesamt_2 (2018); Umweltbundesamt_3 (2018); Umweltbundesamt_4 (2018)). The data show that sulfur dioxid is hardly emitted at all by agriculture and therefore neglectable. They also offer information about current regulations. Germany has agreed (since 2010) to not emit more than 550 thousand tons of ammoniak and 1.08 million tons of nitrogen oxides. Thus, highly desirable and undesirable acidification potentials for BW can be calculated with the following formulars:

$$AP_{HD} = ((550,000 * \frac{E(NH_3)_a}{E(NH_3)_g} * cf_{NH3}) + (1,080,000 * \frac{E(NO_x)_a}{E(NO_x)_g} * cf_{NOx})) * \frac{A_{bw}}{A_g}$$

$$AP_{UD} = (E(NH_3)_a * cf_{NH3} + E(NO_x)_a * cf_{NOx}) * \frac{A_{bw}}{A_g}$$

   With E being current emissions and cf the characterization factor of the recipe method for the respective substances. The subtext a stands for german agriculture, g for total emissions of Germany. A_{bw} describes the area used for agriculture in BW whereas A_g describes the area used for agriculture in Germany.

4. Ecotoxicity

   In the recipe method, ecotoxicity is expressed in 1,4-DCB equivalents. Because 1,4-DCB is sometimes used in pesticides it would make sense to couple ecotoxicological impacts with pesticide regulations. However, neither Germany nor the EU have area based regulations on pesticide usage. The only restriction regards ground water thresholds and pesticide residues on- and in food. But these information would be difficult to relate to recipe's ecotoxicity as it is defined as toxic equivalents emitted to industrial soil (Goedkoop et al., 2009) and processes like plant uptake and percolation are very complex. Still, ecotoxicity is a crucial environmental impact and should therefore not be discarded from the investigation. Hence, a linear classification of desirability was performed, dividing the whole range for ecotoxicity in 5 equally sized sub-ranges.

1.8 Scoring System

For the scoring system used by Blasco et al. (2008), the decision maker needs to define how desirable different magnitudes of objective values are. For this study 5 stages of desirability where chosen: Highly Desirable (), Desirable (), Tolerable (), Undesirable () and Highly Undesirable (). Each of them has a threshold for each objective. They can be ordered into a desirability matrix to get an overview. Now, all points of the pareto front are classified for all objectives, according to desirability thresholds. As result to each point 5 desirability classes are assigned.
In the next step, from HD to HU each of these classes gets a score according to the following formular proposed by Blasco et al. (2008):

$$score(1) = 0$$
$$score(2) = 1$$
$$score(i) = score(i-1) * nobj + 1$$

With score(1) being the score of HD and score(5) being the score of HU. Nobj stands for number of objectives, which in our case is 5 (4 environmental impacts plus mLSS). Finally every point of the pareto front gets a score. It is the sum of all of it's desirabilities' score. The lower the score the better the performance of the point according to this system. To choose one point a set of points (here n = 10) with lowest scoring can be determined. From this set, the point with lowest norm value is chosen.

The scoring system fulfills the ”one vs. others criteria” which was introduced by Messac (1996). According to this criteria ”it is considered better for one criterion to travel across, say, the tolerable region than it is for all the other criteria to travel across the desirable region” (Messac, 1996). In numbers this example can be expressed for two points (A,B) and five objectives as follows:

$$A = (D, D, D, D, UD) = 1 + 1 + 1 + 1 + 31 = 35$$

$$B = (T, T, T, T, T) = 6 + 6 + 6 + 6 + 6 = 30$$

Thus, the scoring assures that none of the objectives performs extremely bad and prefers states, where all objectives are moderate.

2 Detailed Results

2.1 Amount of regionally produced food

2.1.1 MO's optimum

Table 11: Shows the amount (in kiloton) for each product and demand scenario for the respective optimum retrieved by the MO

product	base	vegetarian	vegan
carrots_o	455.7	385.9	426.9
carrots_c	121.5	307.4	257
lettuce_o	300	192.6	229.4
lettuce_c	64.7	164.3	130.2
potato_o	1529.2	1203.7	1276.6
potato_c	330.4	1111.4	986.9
rapeseed_o	38.2	42.8	80.9
rapeseed_c	62.5	241.6	321.1
rye_o	82.1	83	124
rye_c	24	52.4	15.3
soybean_o	1.6	16.5	19.5
soybean_c	0.5	33.4	147.2
sugarbeet_o	1704.2	668.8	718.6
sugarbeet_c	481.5	553.6	480.7
sunflower_o	161	106.5	114.9
sunflower_c	60.5	145.1	170
tomatoes_o	332.2	227.4	253.2
tomatoes_c	71.7	175.6	104.5
wheat_o	499.1	375.3	469.9
wheat_c	194.7	521.2	491.2
broiler_o	0	0	0
broiler_c	0	0	0
egg_o	2.1	0	0
egg_c	2.4	9.3	0
pig_o	0	0	0
pig_c	1.7	0	0
turkey_o	0	0	0
turkey_c	0	0	0
milk_o_p	736.9	102.8	0
milk_c_p	139.5	405	0
milk_o_a	574.1	105	0
milk_c_a	333.6	822.8	0

2.1.2 Maximum LSS

Table 12: Shows the amount (in kiloton) for each product and demand scenario for a state of maximum LSS

product	base	vegetarian	vegan
carrots_o	0	4.8	31.6
carrots_c	678.7	717.6	673.4
lettuce_o	0	1.9	4.6
lettuce_c	366	379.5	380.9
potato_o	0	0	159.2
potato_c	1861.6	2489.1	2348.5
rapeseed_o	0	0	0
rapeseed_c	512.9	530.6	635.9
rye_o	0	0.7	27.1
rye_c	136	135.9	116.1
soybean_o	0	0	0
soybean_c	0.7	2.7	196
sugarbeet_o	0	0	72.8
sugarbeet_c	2708.7	1233.5	1151.4
sunflower_o	0	7.3	9.3
sunflower_c	341.9	339.4	345.1
tomatoes_o	0	0	20.9
tomatoes_c	404.7	426.3	395
wheat_o	0	3.6	77.4
wheat_c	1098.1	1160.9	1093.6
broiler_o	0	0	0
broiler_c	0	0	0
egg_o	0	0	0
egg_c	3	4.5	0
pig_o	0	0	0
pig_c	4.1	0	0
turkey_o	0	0	0
turkey_c	0	0	0
milk_o_p	0	4.6	0
milk_c_p	1283.2	1285.8	0
milk_o_a	0	13	0
milk_c_a	1882.1	1841.1	0

2.2 Demand fulfillment rates

2.2.1 MO's optimum

Table 13: Shows demand fulfillment rates (in percent) for each product cateogry and demand scenario in the respective optimum retrieved by the MO

category	base	vegetarian	vegan
carrots	85	96	95
lettuce	100	92	93
oil	38	35	36
potato	100	93	91
rye	78	94	96
soybean	16	11	22
sugarbeet	81	99	97
tomatoes	100	94	83
wheat	63	77	83
beef	59	0	0
egg	3	7	0
milk	42	33	0
pork	0	0	0
poultry	0	0	0

2.2.2 Maximum LSS

Table 14: Shows demand fulfillment rates (in percent) for each product cateogry and demand scenario in a state of maximum LSS

category	base	vegetarian	vegan
carrots	100	100	98
lettuce	100	98	99
oil	100	57	51
potato	100	100	100
rye	100	95	99
soybean	5	1	26
sugarbeet	100	100	99
tomatoes	100	99	97
wheat	100	100	100
beef	99	0	0
egg	2	3	0
milk	74	71	0
pork	1	0	0
poultry	0	0	0

3 Additional calculations with LSS

As complementary work, maximum LSS values where calculated for districts and counties within BW. Because the issue of LSS maximization is single objective, no MOA was needed. The optimization was performed with a single objective genetic algorithm implemented in the GA package (for R). The values are shown in table and figure 11 and 12 and table 15.

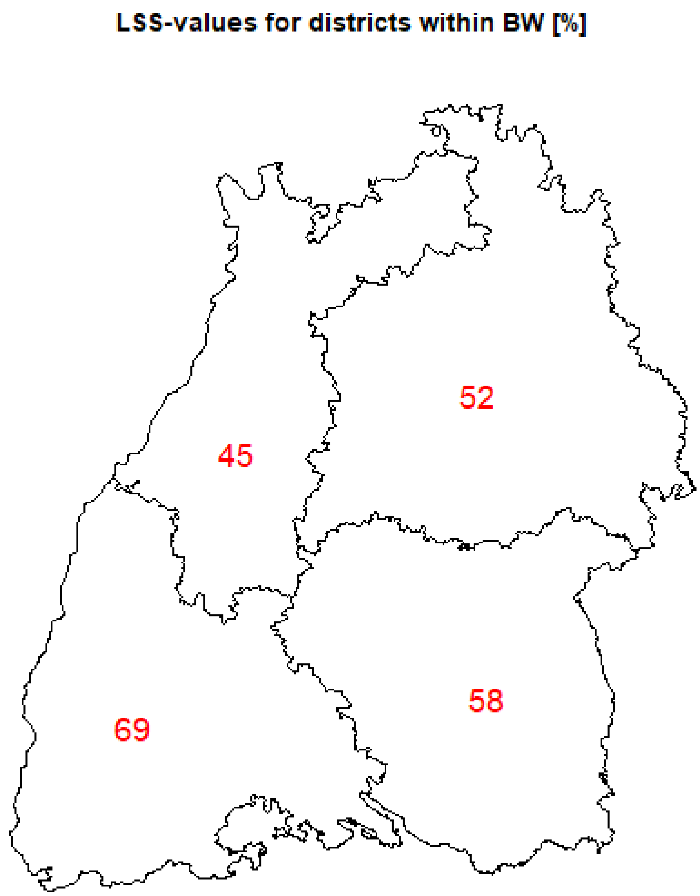

Figure 11: Maximum LSS-values for the 4 districts within BW

Table 15: Maximum LSS-values for different counties within BW.

County	LSS[%]
Stadtkreis Stuttgart	2
Landkreis Böblingen	23
Landkreis Esslingen	15
Landkreis Göppingen	40
Landkreis Ludwigsburg	38
Landkreis Rems-Murr-Kreis	27
Stadtkreis Heilbronn	22
Landkreis Heilbronn	83
Landkreis Hohenlohekreis	66
Landkreis Schwäbisch Hall	71
Landkreis Main-Tauber-Kreis	48
Landkreis Heidenheim	51
Landkreis Ostalbkreis	34
Stadtkreis Baden-Baden	10
Stadtkreis Karlsruhe	5
Landkreis Karlsruhe	59
Landkreis Rastatt	39
Stadtkreis Heidelberg	10
Stadtkreis Mannheim	8
Landkreis Neckar-Odenwald-Kreis	64
Landkreis Rhein-Neckar-Kreis	47
Stadtkreis Pforzheim	2
Landkreis Calw	43
Landkreis Enzkreis	42
Landkreis Freudenstadt	48
Stadtkreis Freiburg im Breisgau	4
Landkreis Breisgau-Hochschwarzwald	78
Landkreis Emmendingen	59
Landkreis Ortenaukreis	60
Landkreis Rottweil	72
Landkreis Schwarzwald-Baar-Kreis	62
Landkreis Tuttlingen	66
Landkreis Konstanz	43
Landkreis Lörrach	31
Landkreis Waldshut	67
Landkreis Reutlingen	47
Landkreis Tübingen	31
Landkreis Zollernalbkreis	62
Stadtkreis Ulm	15
Landkreis Alb-Donau-Kreis	55
Landkreis Biberach	69
Landkreis Bodenseekreis	44
Landkreis Ravensburg	70
Landkreis Sigmaringen	74

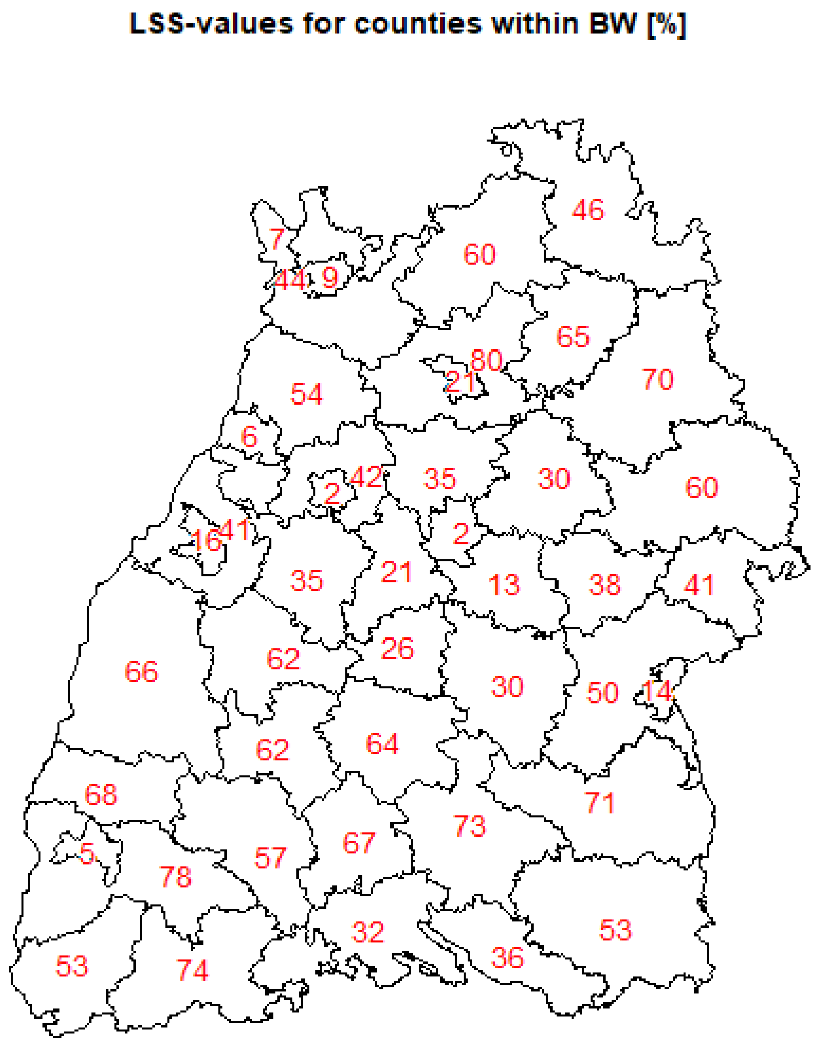

Figure 12: Maximum LSS-values for different counties within BW.

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