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The SOL Model SOLm

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Food system modelling

- Captures **resource use** and **biomass and nutrient flows**, related **commodity production and availability** and related **impacts** on food system level (i.e. regional, national, global)

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Food system modelling - examples of research questions

- How much bioenergy can be sourced from circular food systems and how does this relate to the demand for bioenergy as assumed in IPCC-1.5-degree scenarios?
  - More broadly: scenarios in the context of food-feed-fuel-fibre-fertilizer competition
- Which are the environmental and production impacts on food system level of large-scale implementation of different production systems such as agroforestry or grass-based dairy production?
- Which trade-offs may arise between soil-carbon sequestration, nutrient supply, nutrient surplus, GHG emissions and food production from a large-scale reduction of mineral fertilizers?

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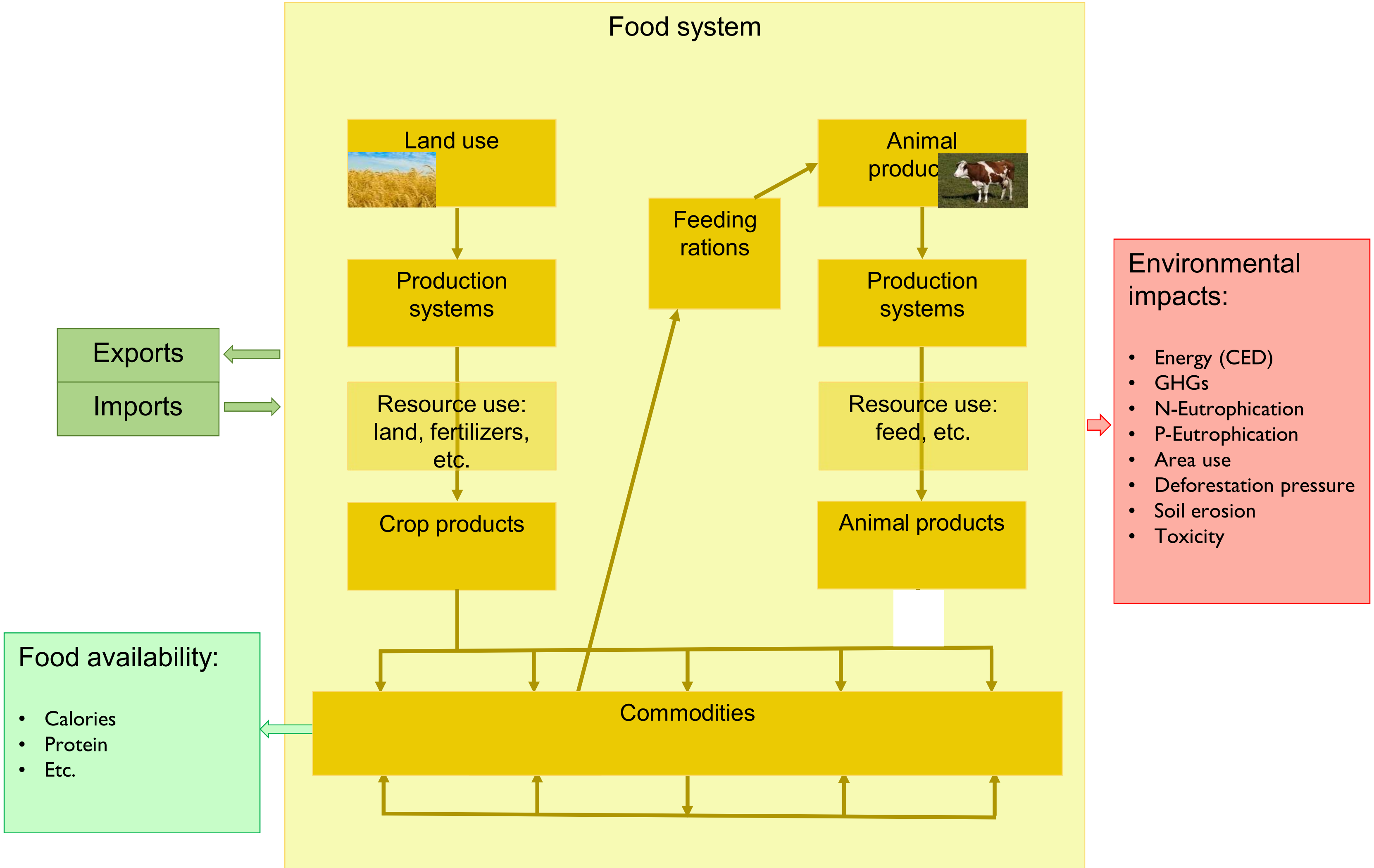
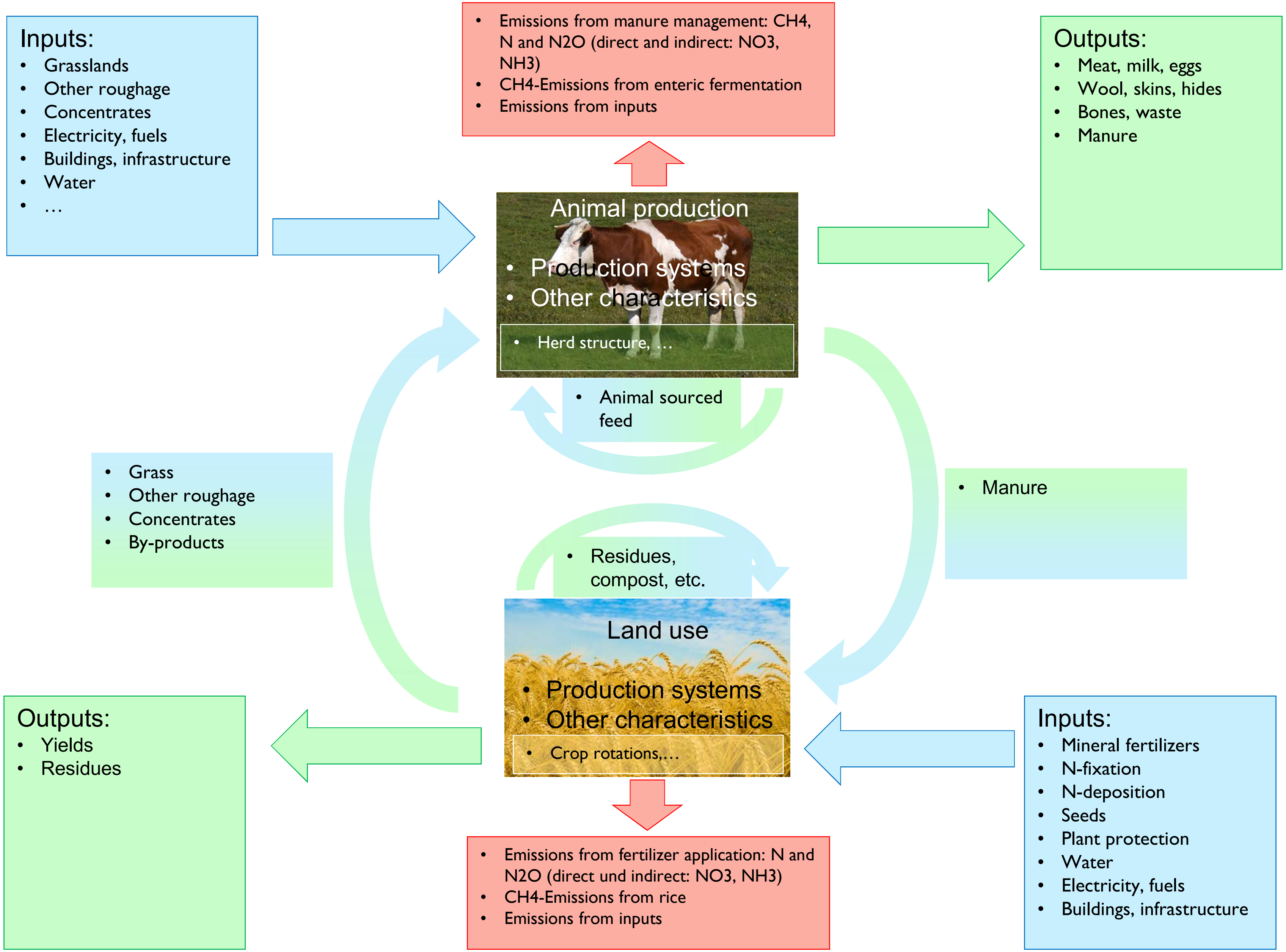
Food system modelling

- Used to
  - assess **trade-offs and synergies** between different aspects of large scale production system changes (e.g. conversion to 60% organic agriculture)
  - compare environmental impacts of **upscaling different production systems** (e.g. circular vs. organic)
  - analyse the impacts and challenges of different **large-scale biomass production and use strategies** (e.g. bioenergy production from agroecological farming systems)
  - identify **key leverage points** for transformation
  - derive **system-level footprints** – compare product-level footprints to system level impacts
    - e.g. GHG emissions per kg human edible protein from a landscape over several crop rotations vs. GHG emissions per kg milk from an intensive dairy production system

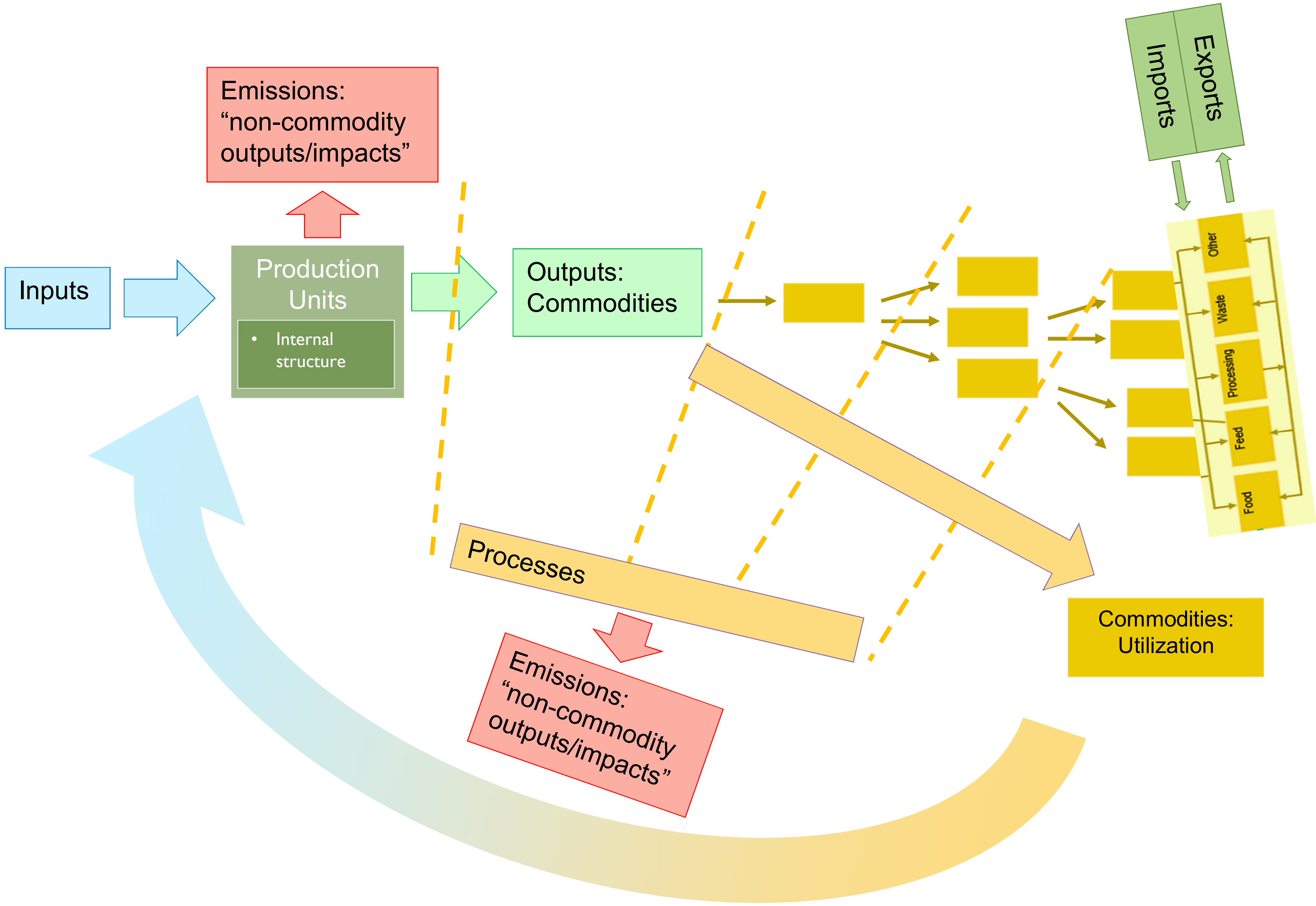

Food system
Land use
Animal production
Feeding rations
Production systems
Production systems
Exports
Imports
Resource use: land, fertilizers, etc.
Resource use: feed, etc.
Crop products
Animal products
Environmental impacts:
Energy (CED)
GHGs
N-Eutrophication
P-Eutrophication
Area use
Deforestation pressure
Soil erosion
Toxicity
Food availability:
Calories
Protein
Etc.
Commodities



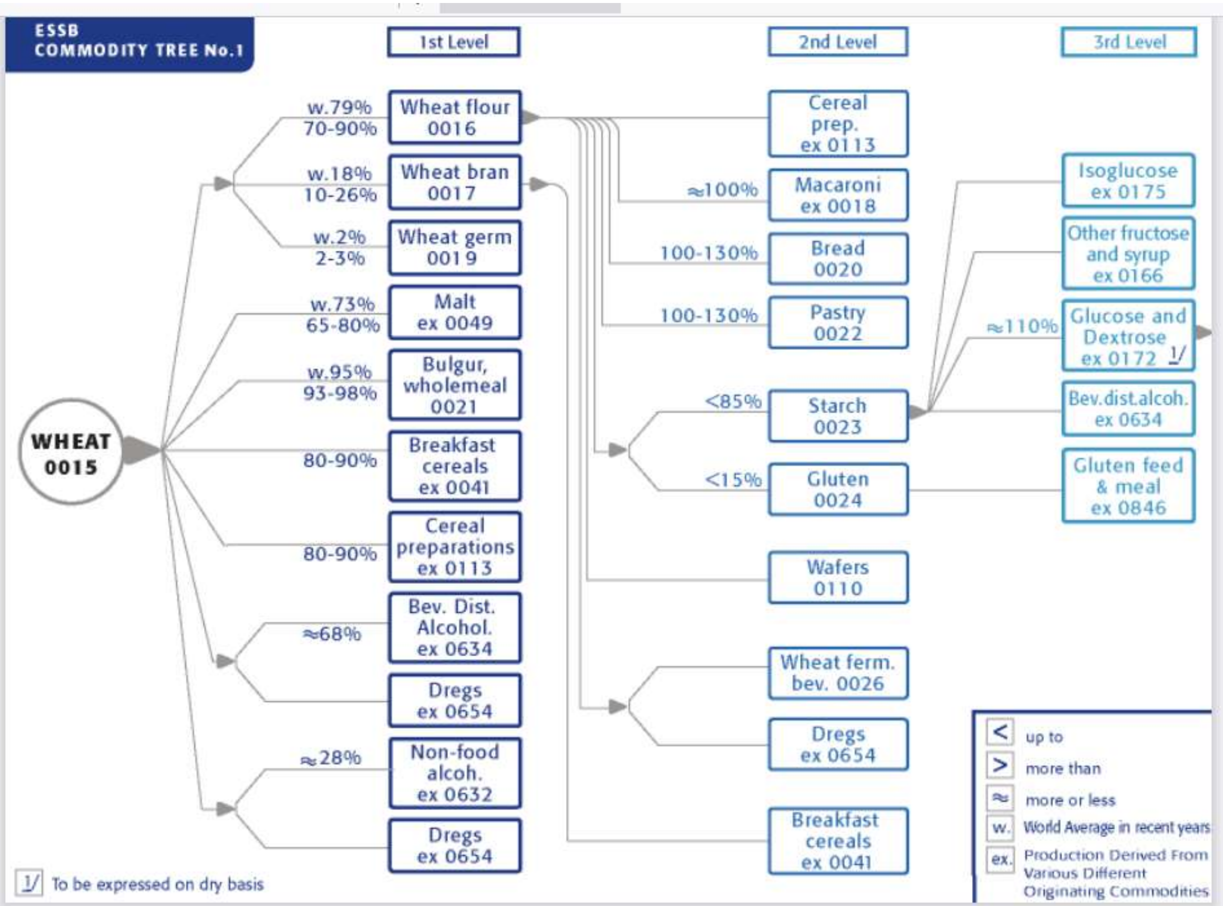
Inputs:
• Grasslands
• Other roughage
• Concentrates
• Electricity, fuels
• Buildings, infrastructure
• Water
• …
• Emissions from manure management: CH4, N and N2O (direct and indirect: NO3, NH3)
• CH4-Emissions from enteric fermentation
• Emissions from inputs
Outputs:
• Meat, milk, eggs
• Wool, skins, hides
• Bones, waste
• Manure
Animal production
• Production systems
• Other characteristics
• Herd structure, …
• Animal sourced feed
• Grass
• Other roughage
• Concentrates
• By-products
• Manure
• Residues, compost, etc.
Land use
• Production systems
• Other characteristics
• Crop rotations,…
Outputs:
• Yields
• Residues
Inputs:
• Mineral fertilizers
• N-fixation
• N-deposition
• Seeds
• Plant protection
• Water
• Electricity, fuels
• Buildings, infrastructure
• Emissions from fertilizer application: N and N2O (direct und indirect: NO3, NH3)
• CH4-Emissions from rice
• Emissions from inputs

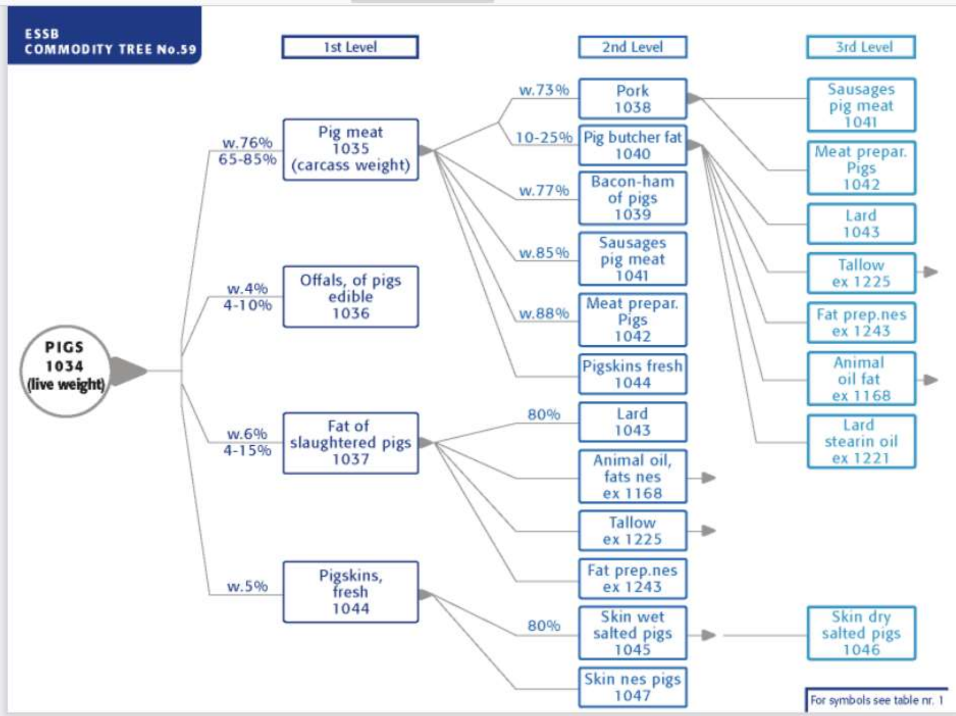
Model and data

- Key entities:
  - **"Production units"** are the key producing physical units (ha of cropland, a producing animal, a volume of aquaculture,…) together with the required actions, technologies, transformations that produce a number of outputs with a number of inputs, thereby also causing emissions and other sustainability impacts.
    - Convert inputs into outputs ("hectare of wheat", "dairy production unit")
    - Have some internal structure (herd structure, crop rotation)
  - **"Commodities"** Outputs from PUs plus commodities derived via processes along the commodity tree; are the physical outputs from production units and derived from those via **"processes"** that describe how outputs are generated from production units and how commodities are transformed into other commodities along the commodity trees (e.g. wheat grain into wheat flour, bran, germ)
  - Commodities are then "**utilized"** for various uses, such as food, feed, energy, waste, etc.
  - PUs and commodities can be linked to **environmental impacts** from the processes involved



Emissions:
“non-commodity
outputs/impacts”
Inputs
Production
Units
Internal
structure
Outputs:
Commodities
Imports
Exports
Other
Waste
Processing
Feed
Food
Processes
Commodities:
Utilization
Emissions:
“non-commodity
outputs/impacts”


ESSB
COMMODITY TREE No.1
1st Level
2nd Level
3rd Level
WHEAT
0015
w.79%
70-90%
Wheat flour
0016
w.18%
10-26%
Wheat bran
0017
w.2%
2-3%
Wheat germ
0019
w.73%
65-80%
Malt
ex 0049
w.95%
93-98%
Bulgur, wholemeal
0021
80-90%
Breakfast cereals
ex 0041
80-90%
Cereal preparations
ex 0113
≈68%
Bev. Dist. Alcohol.
ex 0634
Dregs
ex 0654
≈28%
Non-food alcoh.
ex 0632
Dregs
ex 0654
Cereal prep.
ex 0113
≈100%
Macaroni
ex 0018
100-130%
Bread
0020
100-130%
Pastry
0022
<85%
Starch
0023
<15%
Gluten
0024
Wafers
0110
Wheat ferm. bev. 0026
Dregs
ex 0654
Breakfast cereals
ex 0041
Isoglucose
ex 0175
Other fructose and syrup
ex 0166
≈110%
Glucose and Dextrose
ex 0172 1/
Bev.dist.alcoh.
ex 0634
Gluten feed & meal
ex 0846
< up to
> more than
≈ more or less
w. World Average in recent years
ex. Production Derived From Various Different Originating Commodities
1/ To be expressed on dry basis


ESSB
COMMODITY TREE No.59
1st Level
2nd Level
3rd Level
PIGS
1034
(live weight)
w.76%
65-85%
Pig meat
1035
(carcass weight)
w.4%
4-10%
Offals, of pigs edible
1036
w.6%
4-15%
Fat of slaughtered pigs
1037
w.5%
Pigskins, fresh
1044
w.73%
Pork
1038
10-25%
Pig butcher fat
1040
w.77%
Bacon-ham of pigs
1039
w.85%
Sausages pig meat
1041
w.88%
Meat prepar. Pigs
1042
Pigskins fresh
1044
80%
Lard
1043
Animal oil, fats nes
ex 1168
Tallow
ex 1225
Fat prep.nes
ex 1243
80%
Skin wet salted pigs
1045
Skin nes pigs
1047
Sausages pig meat
1041
Meat prepar. Pigs
1042
Lard
1043
Tallow
ex 1225
Fat prep.nes
ex 1243
Animal oil fat
ex 1168
Lard stearin oil
ex 1221
Skin dry salted pigs
1046
For symbols see table nr. 1

Filter data | Total rows loaded: 2192

	CTProcess	CTProces:	CTInput	CTOutput	CTOutput_Typ	ScenarioN	Region	Extraction
70	Areca_nut_palm_Leaffall	0	Areca_nut_palm	Areca_nut_palm_leaves	Main_Product	Baseline	Luxembourg	0.005
71	Areca_nut_palm_Leaffall	0	Areca_nut_palm	Areca_nut_palm_AbovegroundLivingBiomass	Byproduct	Baseline	Luxembourg	0.85
72	Areca_nut_palm_Leaffall	0	Areca_nut_palm	Areca_nut_palm_BelowgroundLivingBiomass	Byproduct	Baseline	Luxembourg	0.145
73	Arecanuts_Harvest	0	Arecanuts	Arecanuts	Main_Product	Baseline	Luxembourg	1
74	Arecanuts_Pruning	0	Areca_nut_prunings	Areca_nut_prunings	Main_Product	Baseline	Luxembourg	1
75	Artichokes_Harvest	0	Artichokes_crop	Artichokes_fruit	Main_Product	Baseline	Luxembourg	0.6
76	Artichokes_Harvest	0	Artichokes_crop	Artichokes_aboveground_biomass	Byproduct	Baseline	Luxembourg	0.3
77	Artichokes_Harvest	0	Artichokes_crop	Artichokes_roots	Byproduct	Baseline	Luxembourg	0.1
78	Asparagus_Harvest	0	Asparagus	Asparagus	Main_Product	Baseline	Luxembourg	1
79	Asparagus_plant_Leaffall	0	Asparagus_plant	Asparagus_plant_leaves	Main_Product	Baseline	Luxembourg	0.005
80	Asparagus_plant_Leaffall	0	Asparagus_plant	Asparagus_plant_AbovegroundLivingBiomass	Byproduct	Baseline	Luxembourg	0.85
81	Asparagus_plant_Leaffall	0	Asparagus_plant	Asparagus_plant_BelowgroundLivingBiomass	Byproduct	Baseline	Luxembourg	0.145
82	Asparagus_Pruning	0	Asparagus_prunings	Asparagus_prunings	Main_Product	Baseline	Luxembourg	1
83	Avocado_tree_Leaffall	0	Avocado_tree	Avocado_tree_leaves	Main_Product	Baseline	Luxembourg	0.005
84	Avocado_tree_Leaffall	0	Avocado_tree	Avocado_tree_AbovegroundLivingBiomass	Byproduct	Baseline	Luxembourg	0.85
85	Avocado_tree_Leaffall	0	Avocado_tree	Avocado_tree_BelowgroundLivingBiomass	Byproduct	Baseline	Luxembourg	0.145
86	Avocados_Harvest	0	Avocados	Avocados	Main_Product	Baseline	Luxembourg	1
87	Avocados_Pruning	0	Avocado_prunings	Avocado_prunings	Main_Product	Baseline	Luxembourg	1
88	Bambara_beans_ForDryKernels_FlourProduction	1	Bambara_beans_ForDryKernels_kernels	Bambara_beans_ForDryKernels_Flour	Main_Product	Baseline	Luxembourg	0.75
89	Bambara_beans_ForDryKernels_FlourProduction	1	Bambara_beans_ForDryKernels_kernels	Byprod_Bambara_beans_ForDryKernels_Flour	Byproduct	Baseline	Luxembourg	0.25
90	Bambara_beans_ForDryKernels_Harvest	0	Bambara_beans_ForDryKernels_crop	Bambara_beans_ForDryKernels_kernels	Main_Product	Baseline	Luxembourg	0.51
91	Bambara_beans_ForDryKernels_Harvest	0	Bambara_beans_ForDryKernels_crop	Bambara_beans_ForDryKernels_hull	Byproduct	Baseline	Luxembourg	0.11
92	Bambara_beans_ForDryKernels_Harvest	0	Bambara_beans_ForDryKernels_crop	Bambara_beans_ForDryKernels_aboveground_biomass	Byproduct	Baseline	Luxembourg	0.34
93	Bambara_beans_ForDryKernels_Harvest	0	Bambara_beans_ForDryKernels_crop	Bambara_beans_ForDryKernels_roots	Byproduct	Baseline	Luxembourg	0.04
94	Bambara_beans_ForDryKernels_kernels_kernels	1	Bambara_beans_ForDryKernels_kernels	Bambara_beans_ForDryKernels_kernels	Main_Product	Baseline	Luxembourg	1
95	Bananas_Harvest	0	Bananas	Bananas	Main_Product	Baseline	Luxembourg	1
96	Bananas_plant_Leaffall	0	Bananas_plant	Bananas_plant_leaves	Main_Product	Baseline	Luxembourg	0.005
97	Bananas_plant_Leaffall	0	Bananas_plant	Bananas_plant_AbovegroundLivingBiomass	Byproduct	Baseline	Luxembourg	0.85
98	Bananas_plant_Leaffall	0	Bananas_plant	Bananas_plant_BelowgroundLivingBiomass	Byproduct	Baseline	Luxembourg	0.145
99	Bananas_Pruning	0	Banana_prunings	Banana_prunings	Main_Product	Baseline	Luxembourg	1
00	Barley_BarleyMalt	1	Barley_grains	Barley_Malt	Main_Product	Baseline	Luxembourg	0.73
01	Barley_BarleyMalt	1	Barley_grains	Byprod_Barley_Malt	Byproduct	Baseline	Luxembourg	0.27
02	Barley_beer_brewing	2	Barley_Malt	Barley_Beer	Main_Product	Baseline	Luxembourg	0.8
03	Barley_beer_brewing	2	Barley_Malt	Barley_Beer_dregs	Byproduct	Baseline	Luxembourg	0.2
04	Barley_BreakfastCereals_Production	2	Pot_Barley	Barley_BreakfastCereals	Main_Product	Baseline	Luxembourg	1
05	Barley_CoffeeSubstituteProduction	1	Barley_grains	Barley_CoffeeSubstitute	Main_Product	Baseline	Luxembourg	1

E	F
Byproduct	Baseline
Byproduct	Baseline
Byproduct	Baseline
Main_Produ	Baseline
Main_Produ	Baseline
Main_Produ	Baseline
Byproduct	Baseline
Byproduct	Baseline
Byproduct	Baseline
Byproduct	Baseline
Main_Produ	Baseline
Main_Produ	Baseline
Main_Produ	Baseline
Byproduct	Baseline
Byproduct	Baseline
Byproduct	Baseline
Byproduct	Baseline
Main_Produ	Baseline
Main_Produ	Baseline
Main_Produ	Baseline
Byproduct	Baseline
Byproduct	Baseline
Byproduct	Baseline
Byproduct	Baseline
Main_Produ	Baseline
Main_Produ	Baseline
Main_Produ	Baseline
Byproduct	Baseline
Main_Produ	Baseline
Main_Produ	Baseline
Main_Produ	Baseline

55	OtherBirds_Slaughtering	0	OtherBirds	Blood_OtherBirds	Byproduct	Baseline
56	OtherBirds_Slaughtering	0	OtherBirds	Edible_offal_OtherBirds	Byproduct	Baseline

Filter data | Total rows loaded: 33

	CTProcess	CTProces	CTInput	CTOutput	CTOutput Typ	CTProces	CTOutput
	Filter	Filter	coconut	Filter	Filter	Filter	Filter
1	Coconut_CopraAndMilk_AsCopraAndMilk	3	Coconut_CopraAndMilk	Coconut_CopraAndMilk	Main_Product	NULL	NULL
2	Coconut_CopraAsCopra	4	Coconut_Copra	Coconut_Copra	Main_Product	NULL	NULL
3	Coconut_Decarping	1	Coconuts	Coconut_Cleaned	Main_Product	NULL	NULL
4	Coconut_Decarping	1	Coconuts	Coconut_Mesocarp	Byproduct	NULL	NULL
5	Coconut_FatPreparations_Making	5	Coconut_Oil	Coconut_FatPreparations	Main_Product	NULL	NULL
6	Coconut_FattyAcidsOils_Making	5	Coconut_Oil	Coconut_FattyAcidsOils	Main_Product	NULL	NULL
7	Coconut_FattyAcidsOils_Making	5	Coconut_Oil	Water_evaporated	Byproduct	NULL	NULL
8	Coconut_HydrogenatedOilsAndFats_DirectUse	6	Coconut_HydrogenatedOilsAndFats	Coconut_HydrogenatedOilsAndFats	Main_Product	NULL	NULL
9	Coconut_HydrogenatedOilsAndFats_LiquidMargarineMaking	6	Coconut_HydrogenatedOilsAndFats	Coconut_HydrogenatedOilsAndFats_LiquidMargarine	Main_Product	NULL	NULL
10	Coconut_HydrogenatedOilsAndFats_LiquidMargarineMaking	6	Coconut_HydrogenatedOilsAndFats	Water_added	Byproduct	NULL	NULL
11	Coconut_HydrogenatedOilsAndFats_Making	5	Coconut_Oil	Coconut_HydrogenatedOilsAndFats	Main_Product	NULL	NULL
12	Coconut_HydrogenatedOilsAndFats_Making	5	Coconut_Oil	Water_added	Byproduct	NULL	NULL
13	Coconut_HydrogenatedOilsAndFats_MargarineAndShorteningMaking	6	Coconut_HydrogenatedOilsAndFats	Coconut_HydrogenatedOilsAndFats_MargarineAndShortening	Main_Product	NULL	NULL
14	Coconut_HydrogenatedOilsAndFats_MargarineAndShorteningMaking	6	Coconut_HydrogenatedOilsAndFats	Water_added	Byproduct	NULL	NULL
15	Coconut_LiquidMargarine_Making	5	Coconut_Oil	Coconut_LiquidMargarine	Main_Product	NULL	NULL
16	Coconut_LiquidMargarine_Making	5	Coconut_Oil	Water_added	Byproduct	NULL	NULL
17	Coconut_MargarineAndShortening_Making	5	Coconut_Oil	Coconut_MargarineAndShortening	Main_Product	NULL	NULL
18	Coconut_MargarineAndShortening_Making	5	Coconut_Oil	Water_added	Byproduct	NULL	NULL
19	Coconut_NutsAsNuts	2	Coconut_Cleaned	Coconut_Cleaned	Main_Product	NULL	NULL
20	Coconut_Oil_AsOil	5	Coconut_Oil	Coconut_Oil	Main_Product	NULL	NULL
21	Coconut_OilMilling	4	Coconut_Copra	Coconut_Oil	Main_Product	NULL	NULL
22	Coconut_OilMilling	4	Coconut_Copra	Coconut_CakeOfCopra	Byproduct	NULL	NULL
23	Coconut_OilsBoiledDehydrated_Making	5	Coconut_Oil	Coconut_OilsBoiledDehydrated	Main_Product	NULL	NULL
24	Coconut_OilsBoiledDehydrated_Making	5	Coconut_Oil	Water_evaporated	Byproduct	NULL	NULL
25	Coconut_palm_Leaffall	0	Coconut_palm	Coconut_palm_leaves	Main_Product	NULL	NULL
26	Coconut_palm_Leaffall	0	Coconut_palm	Coconut_palm_AbovegroundLivingBiomass	Byproduct	NULL	NULL
27	Coconut_palm_Leaffall	0	Coconut_palm	Coconut_palm_BelowgroundLivingBiomass	Byproduct	NULL	NULL
28	Coconut_Separation	3	Coconut_CopraAndMilk	Coconut_Copra	Main_Product	NULL	NULL
29	Coconut_Separation	3	Coconut_CopraAndMilk	Coconut_Milk	Byproduct	NULL	NULL
30	Coconut_Shelling	2	Coconut_Cleaned	Coconut_CopraAndMilk	Main_Product	NULL	NULL
31	Coconut_Shelling	2	Coconut_Cleaned	Coconut_Shell	Byproduct	NULL	NULL
32	Coconuts_Harvest	0	Coconuts	Coconuts	Main_Product	NULL	NULL
33	Coconuts_Pruning	0	Coconut_prunings	Coconut_prunings	Main_Product	NULL	NULL

CTProces	CTOutput
Filter	Filter
NULL	NULL
NULL	NULL
NULL	NULL
NULL	NULL
NULL	NULL
NULL	NULL
NULL	NULL
NULL	NULL
NULL	NULL
NULL	NULL
NULL	NULL
NULL	NULL
NULL	NULL
NULL	NULL
NULL	NULL
NULL	NULL
NULL	NULL
NULL	NULL
NULL	NULL

Source on Save Run Sour

```
     #sum over the same outputs from different processes (e.g. wheat grains arise from winter and summer wheat harvest, etc. )
     #  as otherwise, a many-to-many-relationship is present in subsequent calculations, disrupting results
     #ideally, this would be done with rm.na=TRUE in the across-statement, but this makes it terribly slow and DOES NOT WORK
     #  (NA still present and resulting in a sum with it being NA as well) - hence the roundabout via filter(!is.na()) - this works and is fast
       filter(!is.na(DAQ)) %>%
       group_by(CTOutput,Region) %>%
        summarise(across(c(DAQ), sum)) %>%
       ungroup()

     input_data_2 <- input_data %>%
      filter(is.na(CTLevel0Input_Quantity)) %>%
      select(-c("CTLevel0Input_Quantity")) %>%
      left_join(filling_data,by = c("Region","CTInput" = "CTOutput"))%>%
     #DAQ from the previous level in the input to this level
      rename(CTLevel0Input_Quantity = DAQ)

     output_level <- input_data_2 %>%
      #derive the output commodity quantity from a process by multiplying the input quantity
      #with the share that goes into this process and the extraction rate of this commodity in this process
      mutate(CTLevel0Output_Quantity = CTLevel0Input_Quantity * CT_Shares * ExtractionRates ) %>%
      # Derive Domestically Available Quantities DAQ = Production + Imports - Exports
      mutate(DAQ = CTLevel0Output_Quantity + CTOutput_TotalImportQuantity - CTOutput_TotalExportQuantity)

    } ### end if l > 0

    ####################################
    #################### write for each l
    ### writing level output in the final output
    CT_CalculationResults <- rbind(CT_CalculationResults, output_level)
```

2:1 6. Derive N excretion for lactating dairy cattle - LUXEMBOURG case

SOLm technicalities

- Originally coded in GAMS (SOLm versions 1 to 6)
- Software for the current version:
  - recoded in R
  - data organization in SQLite
  - inputs via excel, csv or R

SOLm structure and basic functioning

- SOLm **does not involve optimization**, but is driven by a social planner – this has a number of (dis-)advantages
  - many assumptions are to be made "by hand"
    - generally driven by "ceteris paribus" assumptions: "all else equal"
  - baseline/calibration is relatively easy
  - avoiding corner solutions
  - "realistic scenarios" vs. optimal ones
  - multiple maxima in option spaces
  - very flexible and detailed, etc.
  - fast

SOLm data

- The model is fed with and calibrated by a large number of different data, e.g. from
  - FAOSTAT
  - IPCC guidelines for GHG inventories 2006/2019
    - National GHG inventories
  - National nitrogen balances
  - Various publications with global datasets (e.g. erosion, gridded yield suitability data, etc.)
  - etc.

SOLm structure and basic functioning

- **Preparatory files**
  - generic structure of SOLm generated in R/excel and stored in SQLite
  - original data taken from various sources,

    stored in excel and then loaded to R or

    directly loaded to R (e.g. FAOSTAT)
  - data processing, preparation in R – keep the data as raw as possible
  - all data is stored in SQLite

SOLm_ReadFAOSTAT.R
SOLm_ReadIPCCData.R
SOLm_ReadLuxembourgData.R
SOLm_ReadSwitzerlandData.R
SOLm_BasicStructure.R

```
##### 1.Run basic scripts ----------------------------------------------------
#the following script loads the packages required and sets the path
source("SOLm_LoadPackagesAndDefinePaths.R")

#this loads some general data that is always needed from the general database SOL_Bas
source("SOLm_LoadAndDeriveGeneralInformation.R")
##############ATTENTION:
#In case additional commodities, regions etc. that are not present in this basic data
# these need to be added to the sets generated in this code, as otherwise they are mi
# This is either done in the scenario specification
# or it is done before, adding them to the basic data to then have them always availa
##############ATTENTION:

#this code specifies all functions that are needed in SOLm
source("SOLm_Functions.R")

##### End of: 1.Run basic scripts ----------------------------------------.
```

- **Scenario files**
  - load data from SQLite
  - do parameter and other choices and assumptions as needed
  - transform into the form required by the core model code

```
# 2.3 Luxembourg baseline scenario
#a scenario based on Luxembourg data, for the project SustEATable; basic scenario to develop the
source("SOLm_Scenario_LuxembourgDataBaseline.R")

##### End of: 2.Run scenario assumptions ------------------------------------------.
```

SOLm structure and basic functioning

- **Core model files**
  - derive domestically available quantities and their utilization from production unit numbers
  - derive production unit numbers and yields if not provided at the beginning
  - calculate outputs and impacts

```
##### 3.Run the core code -----------------------------------
#the following scripts contain the core model code

source("SOLm_CTCalculations.R")

##### End of: 3.Run the core code ---------------------------
```

SOLm_GHGInventoryCalculations.R

- **Post processing**
  - output files
  - figures and tables
  - etc.

Option space and scenarios

- How to tell the stories – narratives - communication
- SOLm allows to line out the option space of future agriculture and food systems
- The **option space** is the totality of all options that emerge from combining different levels along a number of different key dimensions, e.g.
  - yields
  - share of organic production
  - level of reduction in food-competing feed for animals
  - level of food waste reduction
  - diets
  - GHG mitigation goals
  - etc.

Option space and scenarios

- Each option in the option space can then be assessed according to their performance regarding various indicators, such as e.g.
  - land use
  - deforestation
  - nitrogen surplus
  - GHG emissions
  - biodiversity pressures
  - etc.

Example of an option space

Scenarios are combinations of

- Different shares of organic production (0 to 100%)
- Different reduction levels of feed production on croplands (0 to 100%)
- Different levels of waste reduction (0 to 50%)
- Different assumptions on impact of climate change on yields (zero to high)

This results in 6*3*3*3 = 162 scenarios

Example: **Cropland use** (global values, relative to BAU 2050)

- > +5%
- < +5% > -5%
- <−5%

Climate change impact on yields

% Wastage reduction	% Reduction in food-competing feed	Zero: % Organic 0	20	40	60	80	100	Medium: % Organic 0	20	40	60	80	100	High: % Organic 0	20	40	60	80	100
0	0	0	5	10	17	25	33	21	26	33	40	47	57	46	50	54	58	64	71
0	50	−16	−12	−8	−4	2	8	2	7	10	16	22	27	25	26	29	32	35	40
0	100	−26	−24	−20	−16	−12	−8	−9	−6	−3	1	5	9	12	13	14	15	17	20
25	0	−6	−1	5	10	18	26	14	20	25	32	40	48	39	42	45	50	56	61
25	50	−22	−18	−13	−8	−4	−2	−4	0	5	9	14	21	18	20	22	25	27	32
25	100	−30	−27	−25	−21	−17	−13	−14	−11	−8	−5	−1	4	6	7	8	8	10	13
50	0	−11	−7	−1	5	11	20	8	13	18	25	32	40	30	34	38	42	47	53
50	50	−25	−23	−19	−14	−9	−4	−9	−6	−2	3	8	14	10	12	15	17	21	25
50	100	−35	−32	−29	−25	−22	−18	−19	−17	−13	−10	−7	−3	−1	0	1	3	4	7

Muller et al. 2017

Example of an option space

Similar for **nitrogen surplus** per hectare

This allows to identify viable options, where the advantages and drawbacks of the different strategies balance

Patterns:

- Organic: more land use, less N surplus, danger of N undersupply
- Waste reduction: less land use, danger of N undersupply
- Concentrate feed reduction: Less land use, reduced N surplus
- Climate Change impact: more land use

% Wastage reduction	% Reduction in food-competing feed	Climate change impact on yields: Zero, % Organic 0	20	40	60	80	100	Medium, % Organic 0	20	40	60	80	100	High, % Organic 0	20	40	60	80	100
0	0	0	5	10	17	25	33	21	26	33	40	47	57	46	50	54	58	64	71
	50	−16	−12	−8	−4	2	8	2	7	10	16	22	27	25	26	29	32	35	40
	100	−26	−24	−20	−16	−12	−8	−9	−6	−3	1	5	9	12	13	14	15	17	20
25	0	−6	−1	5	10	18	26	14	20	25	32	40	48	39	42	45	50	56	61
	50	−22	−18	−13	−8	−4	−2	−4	0	5	9	14	21	18	20	22	25	27	32
	100	−30	−27	−25	−21	−17	−13	−14	−11	−8	−5	−1	4	6	7	8	8	10	13
50	0	−11	−7	−1	5	11	20	8	13	18	25	32	40	30	34	38	42	47	53
	50	−25	−23	−19	−14	−9	−4	−9	−6	−2	3	8	14	10	12	15	17	21	25
	100	−35	−32	−29	−25	−22	−18	−19	−17	[illegible]	[illegible]	[illegible]	−3	−1	0	1	3	4	7

3

> +5%

< +5%
> -5%

<−5%

% Wastage reduction	% Reduction in food-competing feed	Climate change impact on yields: Zero, % Organic 0	20	40	60	80	100	Medium, % Organic 0	20	40	60	80	100	High, % Organic 0	20	40	60	80	100
0	0	25	21	15	10	4	−3	23	19	14	8	3	−3	21	16	12	7	1	−4
	50	20	16	12	7	2	−4	18	14	10	6	1	−4	17	13	9	4	0	−5
	100	15	11	7	3	−1	−5	13	10	7	3	−1	−5	12	9	5	2	−2	−6
25	0	23	19	14	8	2	−4	21	17	12	7	1	−4	19	15	10	5	0	−5
	50	18	14	10	6	1	−5	17	13	9	5	0	−5	15	11	7	3	−1	−5
	100	13	10	6	2	−2	−6	12	9	5	2	−2	−6	11	8	4	1	−3	−6
50	0	21	17	12	7	1	−5	19	15	10	5	0	−6	17	13	9	4	−1	−6
	50	16	12	8	4	0	−6	15	11	7	3	−1	−6	14	10	6	2	−2	−6
	100	11	8	5	1	−3	−7	10	7	[illegible]	[illegible]	[illegible]	−7	10	7	3	0	−3	−7

3

> 10kg/ha	Surplus
between 10 and 5kg/ha	Optimal
between +5 and -5 kg/ha	Critical
<-5kg/ha	Deficit

Muller et al. 2017

Option space and scenarios

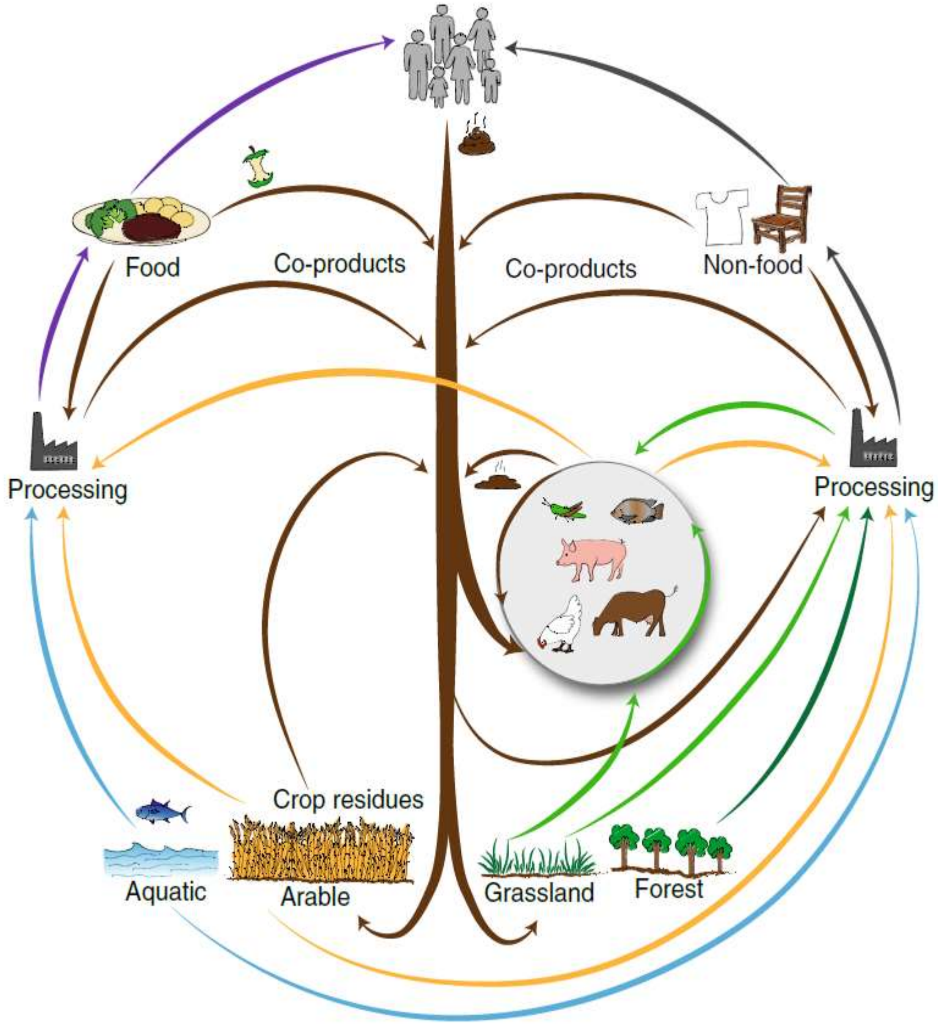
- **Scenarios** are certain areas in the option space that are amended by a detailed description of the socio-economic dynamics that may drive them, e.g. regarding:
  - policies
  - preferences
  - economic development
  - etc.
- Scenarios are thus telling selected stories/narratives for these special options in the option space

Example of a scenario – the circular food system:

- **Animals only eat biomass that cannot be eaten by humans**
  - croplands are primarily used for food production;
  - no feed production on croplands besides the areas needed due to agronomic reasons (e.g. for plant protection and soil fertility in organic systems)
- **Waste flows are recycled as fertilizers**
- **Reduced external inputs** (imported feed; mineral fertilizers)

Examples of results:

  - calorie and protein output of such a system, GHG emissions and nutrient balances, etc.
  - simple socio-economic indicators: costs, labour use, labour productivity (just indicative, no economic equilibrium model)
  - trade-offs and synergies, e.g.
    - between lower yields and increased land use
    - between reduced nitrogen inputs and surplus and sufficient nitrogen supply
    - between reduced concentrate feed for ruminants and increased GHG emissions per kg milk
    - between reduced animal source products and health aspects of diets



Muscat et al. 2021

Challenges and opportunities

- **Challenges**
  - combine different partly inconsistent data sources
  - lots of assumptions, often on very aggregate level (national, global)
  - no optimization
  - no internal decision structure; no socio-economic dynamics
- **Opportunities**
  - demand for such food system analyses (single countries, etc.)
  - very flexible, encompassing and detailed
  - transparent
  - no optimization

Current state

- The commodity tree works
- Ongoing implementation of GHG emission calculations:
  - Inventories for Luxembourg and Switzerland (SustEATable and a master thesis at the University of Basel)
- Basic documentation available (LaTex)
- Ongoing discussion on workflow organization
  - versioning, Github/Bitbucket
  - code guidelines and conventions, folder structure, etc.
  - R markdown /Quarto
  - accessible documentation, also with graphical elements on the structure and workflows
  - how to work on it together: coding separate modules, etc. (e.g. for GHG emissions based on the IPCC inventory guidelines)
- Used in a number of projects: DeliDiets, Pathways, trans4num, Sprint, Feast, InBestSoil, Spoc, Vision2050,…