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Food system modelling – the SOL model

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Food system modelling

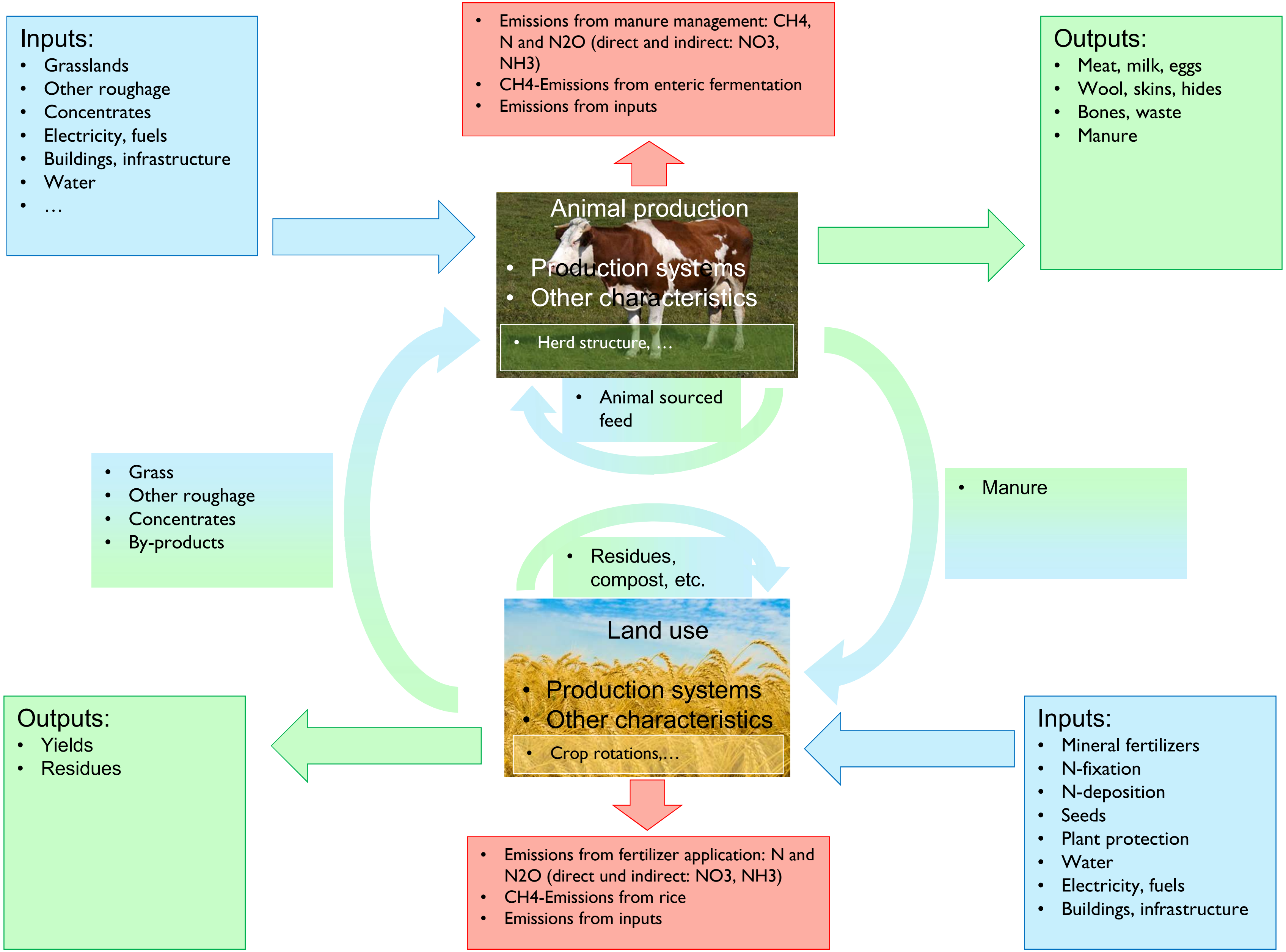
- Captures **resource use** and **biomass and nutrient flows**, related **commodity production and availability** and related **impacts** on food system level (i.e. regional, national, global)

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?
- 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?

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



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

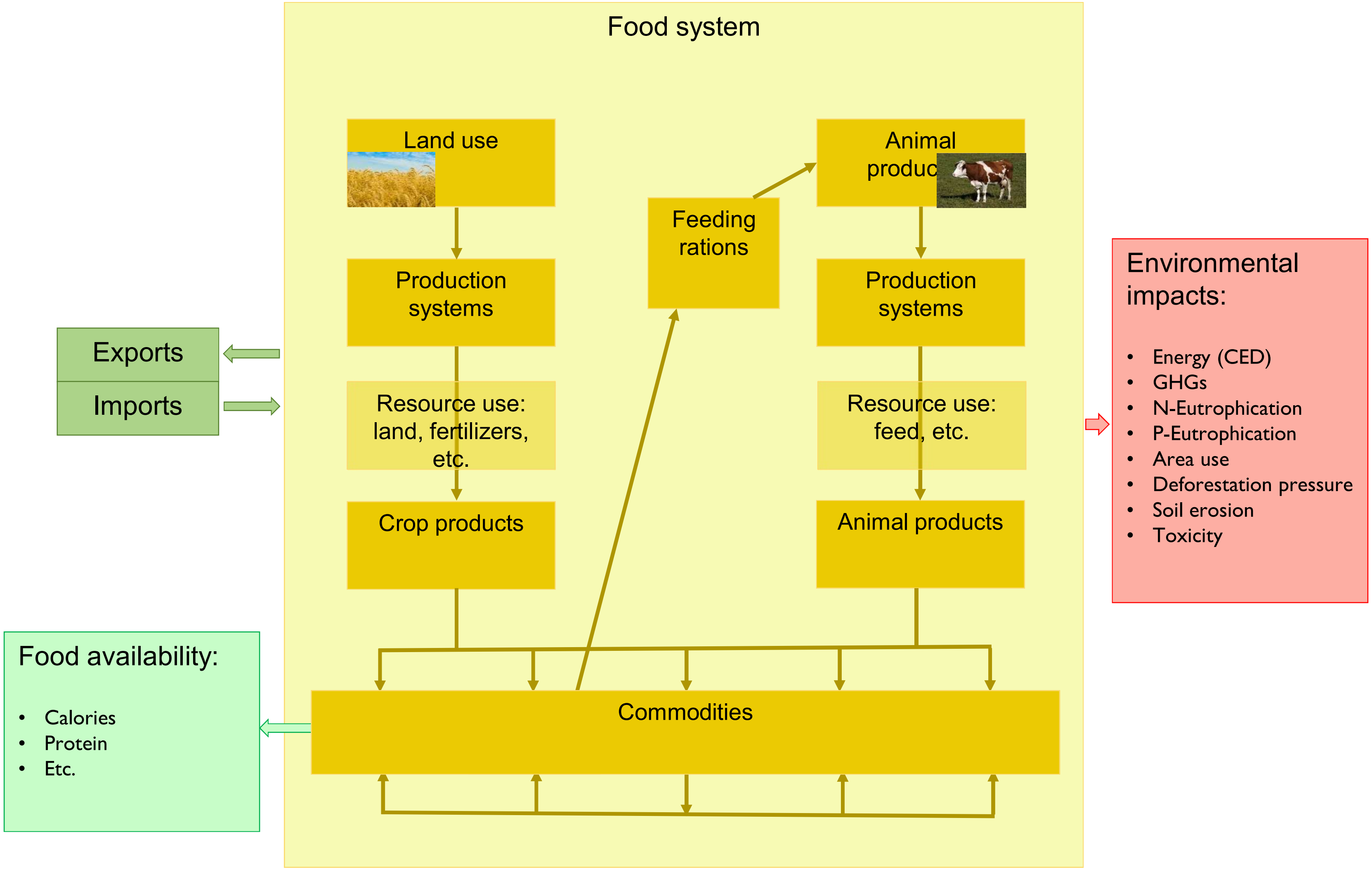
- Residues, compost, etc.

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



Food system

Land use

Feeding rations

Animal production

Production systems

Production systems

Exports

Imports

Resource use: land, fertilizers, etc.

Resource use: feed, etc.

Crop products

Animal products

Commodities

Food availability:

- Calories
- Protein
- Etc.

Environmental impacts:

- Energy (CED)
- GHGs
- N-Eutrophication
- P-Eutrophication
- Area use
- Deforestation pressure
- Soil erosion
- Toxicity

Model and data

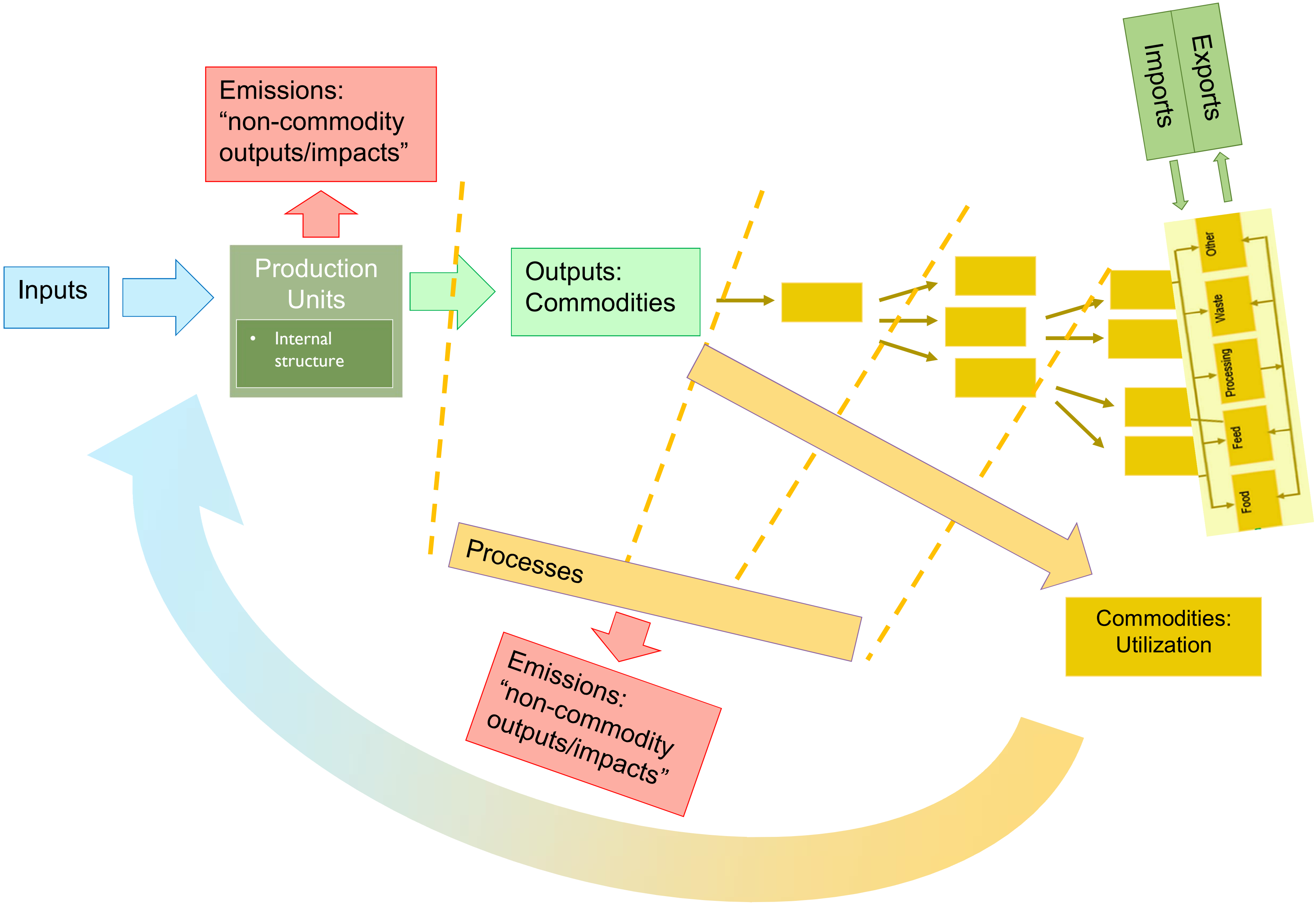
- Key entities:

  - **"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
Emissions:
“non-commodity
outputs/impacts”
Commodities:
Utilization

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, linked to the generic structure

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

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

- **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)

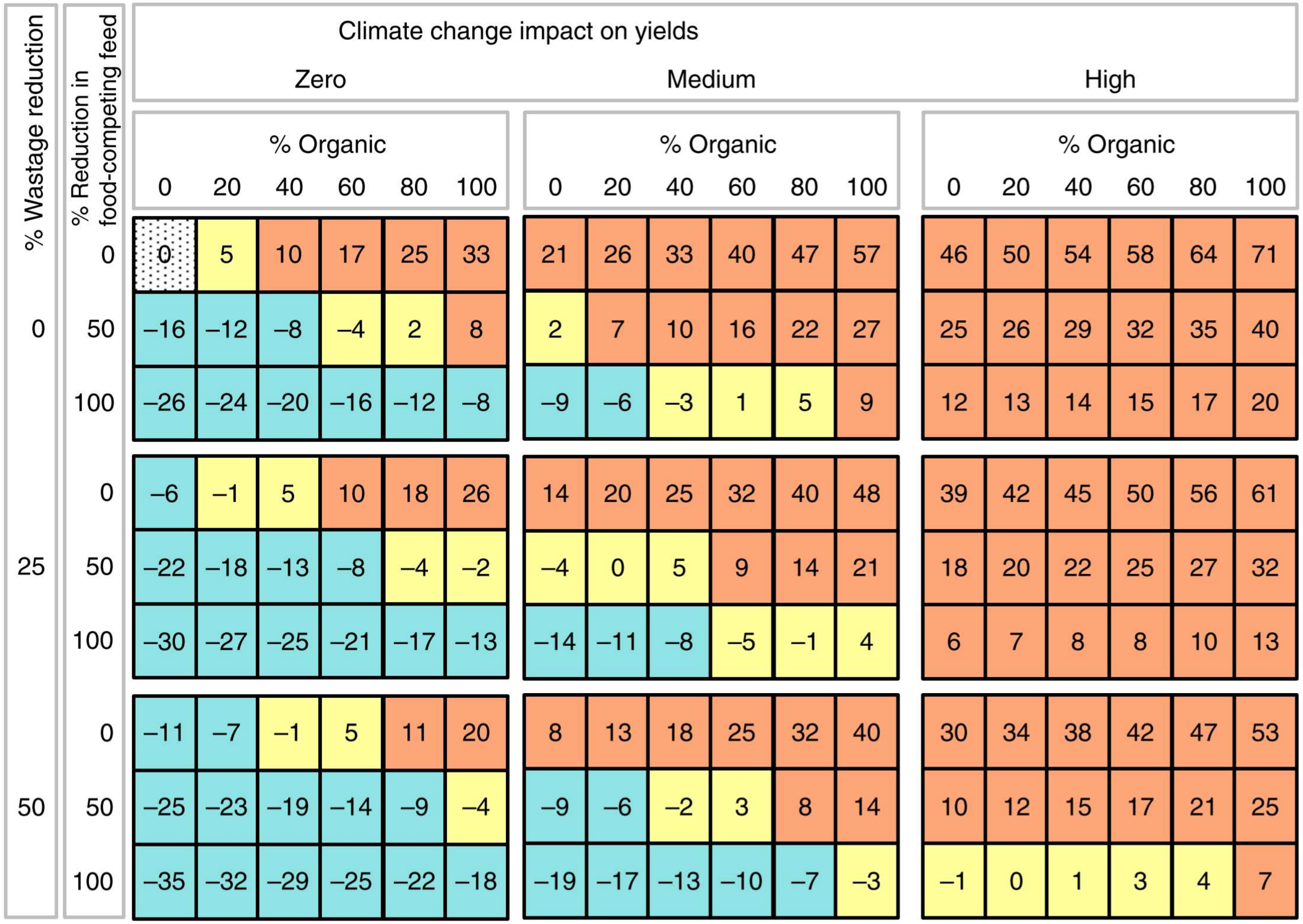
This results in 6*3*3*3 = 162 scenarios

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

🟧 > +5%

🟨 < +5% > -5%

🟦 <−5%



% Wastage reduction	% Reduction in food-competing feed	Climate change impact on yields																	
		Zero						Medium						High					
		% Organic						% Organic						% Organic					
		0	20	40	60	80	100	0	20	40	60	80	100	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	–13	–10	–7	–3	–1	0	1	3	4	7

Muller et al. 2017

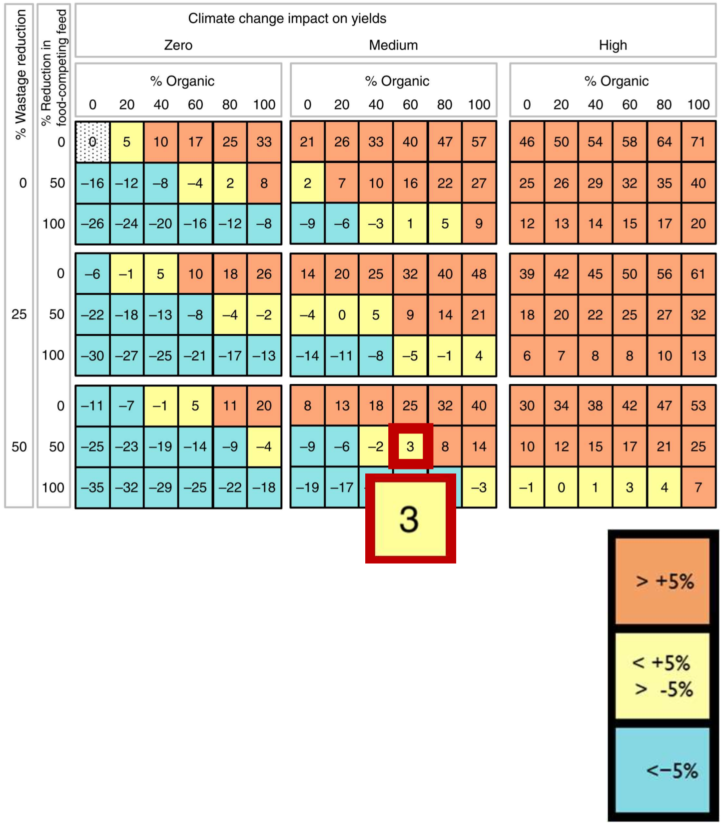
Example of an option space

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



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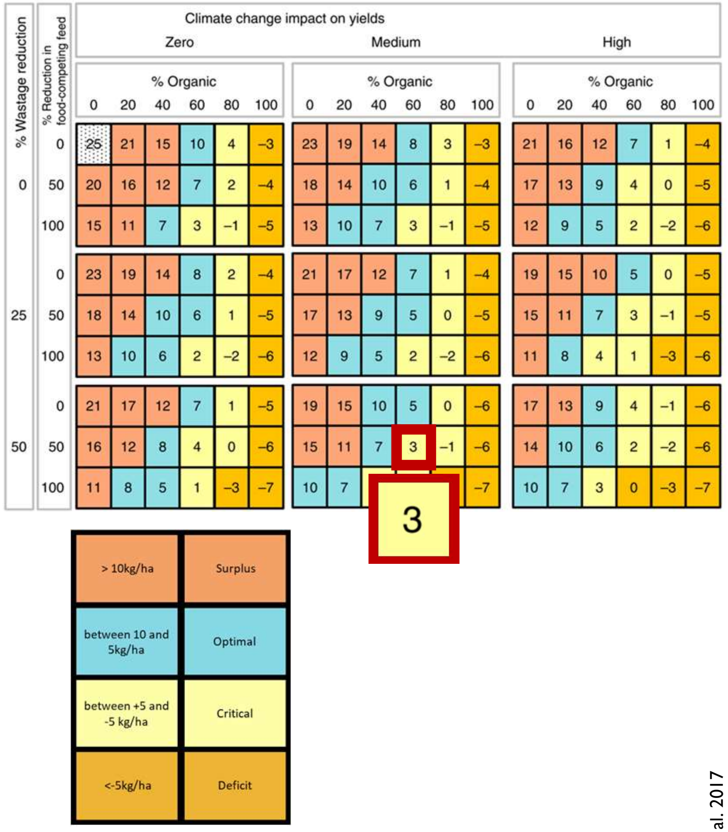
25	0	–6	–1	5	10	18	26	14	20	25	32	40	48	39	42	45	50	56	61
	50	–22	–18	–13	–8	–4	–2	–4	0	5	9	14	21	18	20	22	25	27	32
	100	–30	–27	–25	–21	–17	–13	–14	–11	–8	–5	–1	4	6	7	8	8	10	13
50	0	–11	–7	–1	5	11	20	8	13	18	25	32	40	30	34	38	42	47	53
	50	–25	–23	–19	–14	–9	–4	–9	–6	–2	3	8	14	10	12	15	17	21	25
	100	–35	–32	–29	–25	–22	–18	–19	–17	[illegible]	[illegible]	[illegible]	–3	–1	0	1	3	4	7

3

> +5%

< +5%
> -5%

<−5%



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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

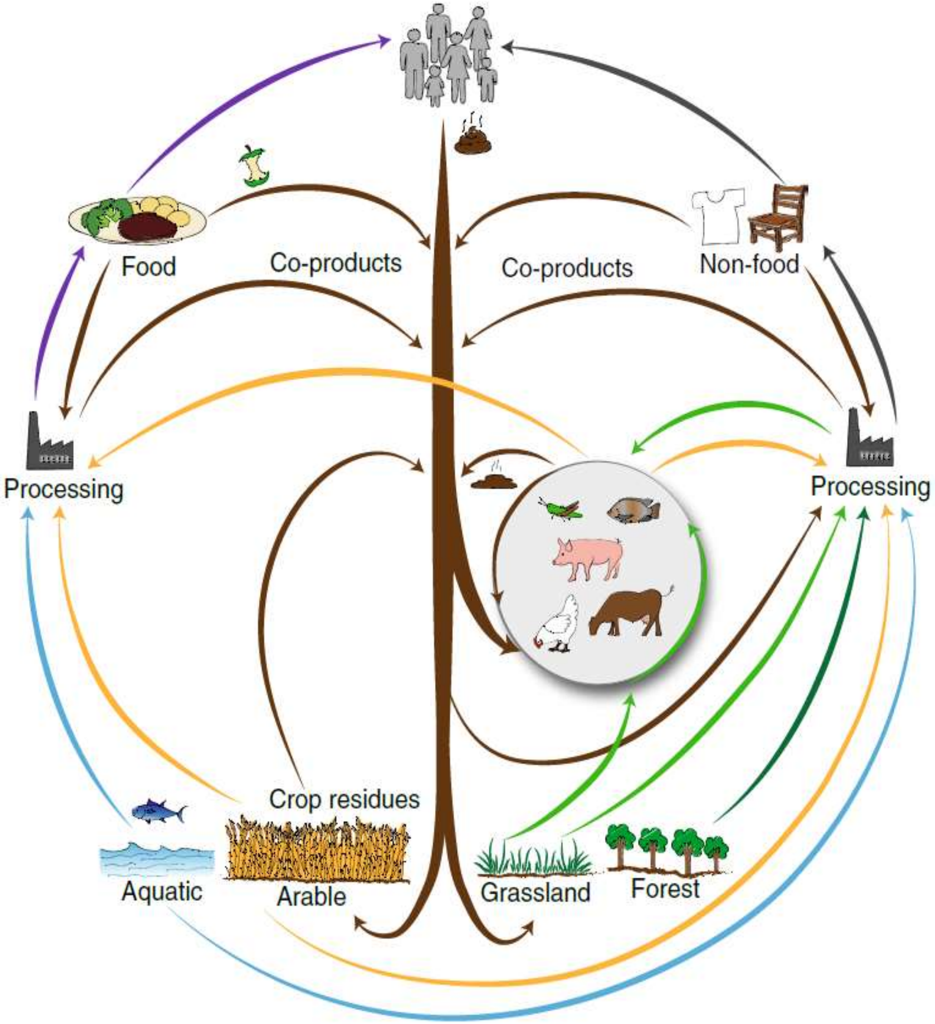
- **Scenarios** are certain areas in the option space that are amended by a detailed description of the socio-economic dynamics that may drive them, e.g. regarding:
  - policies
  - preferences
  - economic development
  - etc.
- Scenarios are thus telling selected stories/narratives for these special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

SOLm further/parallel development

- **LEAF**
  - Food system modelling on landscape level / within a landscape context
  - e.g. for site-adapted policy support

- **GEO-SOL**
  - Downscale food-system level impacts to a grid and relate this to ecosystem-contexts

- **Optimization**
  - Code/combine the modules such as to allow for optimization