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# Agricultural Production Systems

A joint initiative of the ETH domain and Swiss Federal Offices

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EPFL Lausanne

# Agricultural Production Systems


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# Overview: Agricultural Systems

- Introduction (T. Nemecek)
- Agricultural Buildings (S. Erzinger)
- Agricultural Machinery and Field Work Processes (S. Erzinger) →*Questions*
- Inputs from Industry (Fertilisers, Pesticides; T. Nemecek)
- Agricultural Inputs (Seed, Feedstuffs; T. Nemecek) → *Questions*
- Agricultural Products (Arable Crop Production, T. Nemecek)
- Conclusions and Discussion (T. Nemecek)

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# The Swiss Federal Research Stations FAL Reckenholz und FAT Taenikon

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- Fields of activity in LCA:
  - Methodology development for agriculture: emissions, biodiversity, soil quality
  - LCI: databases ecoinvent and SALCA
  - Applications: farms, arable crops and fodder production, animal products
- Participants at the compilation of the ecoinvent-datasets:
  Thomas Nemecek, Sebastiano Meier, Angelika Heil and Olivier Huguenin (FAL Reckenholz)
  Stefan Erzinger, Albert Zimmermann, Dunja Dux and Silvio Blaser (FAT Taenikon)

# Overview: Datasets

| Production branches | Buildings | Machinery | Work processes | Inputs | Products |
|---|---|---|---|---|---|
| Arable crops | ■ | ■ | ■ | ■ | ■ |
| Fodder crops | ■ | ■ | ■ | ■ | ▫ |
| Horticulture (Field) | ■ | ▫ | ▫ | ■ | |
| Horticulture (Greenhouse) | | ▫ | ▫ | ■ | |
| Fruit growing | ▫ | ▫ | ▫ | ■ | |
| Vineyards | ▫ | ▫ | ▫ | ■ | |
| Cattle production | ■ | ■ | ■ | ■ | |
| Pig production | ■ | ■ | ■ | ■ | |
| Poultry production | | ▫ | ▫ | ■ | |

■ relevant datasets available
▫ partly available
not available

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# Overview: Datasets

| | Subcategory | Number of modules | Example of inventories for the subcategories | | |
|---|---|---|---|---|---|
| | | | Name | Location | Unit |
| Infra-structure | Buildings | 13 | dried roughage store, air dried, solar | CH | kg |
| | | | label housing system, pig | CH | pig place |
| | Machinery | 6 | agricultural machinery, tillage, production | CH | kg |
| Operation of infrastructure | Building usage | 8 | loose housing system, cattle, operation | CH | LU |
| | | | dried roughage store, air dried, solar, operation | CH | kg |
| | Machinery and equipment usage | 33 | haying, by rotary tedder | CH | ha |
| | | | tillage, ploughing | CH | ha |
| | | | milking | CH | kg |
| | Drying | 4 | grain drying, high temperature | CH | kg |
| Agricultural inputs | Mineral fertilisers | 24 | lime, from carbonation, at regional storehouse | CH | kg |
| | | | ammonium nitrate, as N, at regional storehouse | RER | kg |
| | | | urea, as N, at regional storehouse | RER | kg |
| | Organic fertilisers | 6 | horn meal, at regional storehouse | CH | kg |
| | Pesticides | 68 | cyclic N-compounds, at regional storehouse | RER | kg |
| | | | [Sulfonyl]urea-compounds, at regional storehouse | CH | kg |
| | | | pesticide unspecified, at regional storehouse | CH | kg |
| | Seed | 22 | sugar beet seed IP, at regional storehouse | CH | kg |
| | Feed | 10 | wheat organic, at fodder mill | CH | kg |
| | | | wheat IP, at fodder mill | CH | kg |
| Agricultural outputs | Plant production | 59 | potatoes organic, at farm | CH | kg |
| | | | rape seed extensive, at farm | CH | kg |
| | | | hay intensive IP, at farm | CH | kg |
| | Animal production | 1 | tallow, at plant | CH | kg |
| | Total | 254 | | | |

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# Importance of Infrastructure in LCAs for Agricultural Systems

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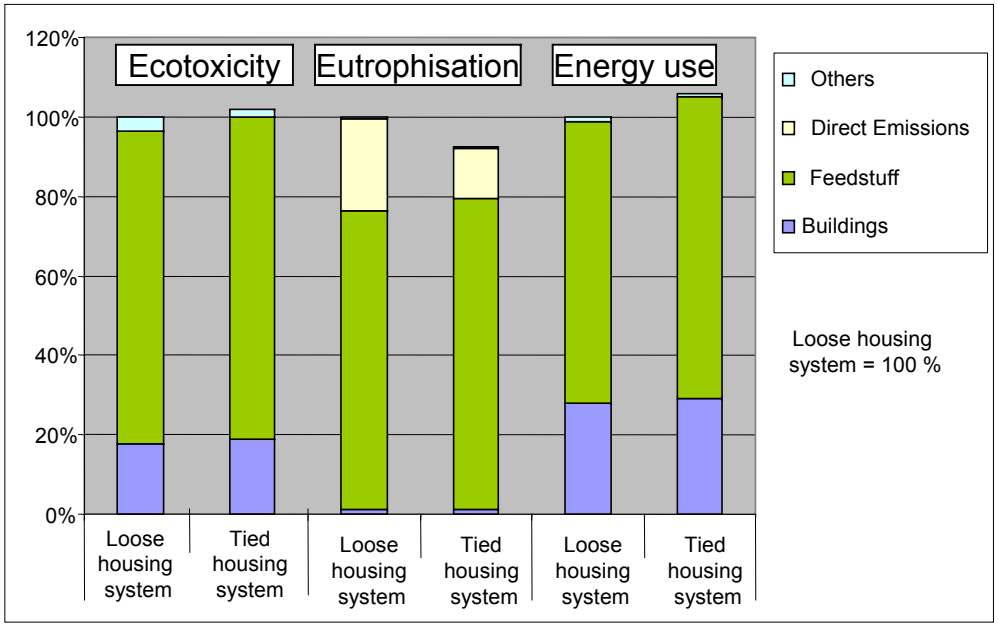
- Existing LCAs of agricultural products show that the infrastructure contributes around 30% to different impacts




- Importance of the utilisation rate

  Many agricultural machines and equipment have a low utilisation rate per year (e.g. only 30 h per year)

# Overview

| Categories | | # | Examples |
|---|---|---|---|
| Buildings | Infrastructure | 12 | Loose housing, cattle; fully slatted floor, pigs; silo, shed |
| | Operation | 9 | Loose housing, cattle; fully slatted floor, pigs; milking |
| Machinery | | 6 | Tractor; combine harvester; agricultural machinery, tillage |
| Drying | | 4 | Grass drying; grain drying |
| Field work processes | | 32 | Ploughing, fertilising, mowing, harvesting, potato |
| | | Σ 63 | |

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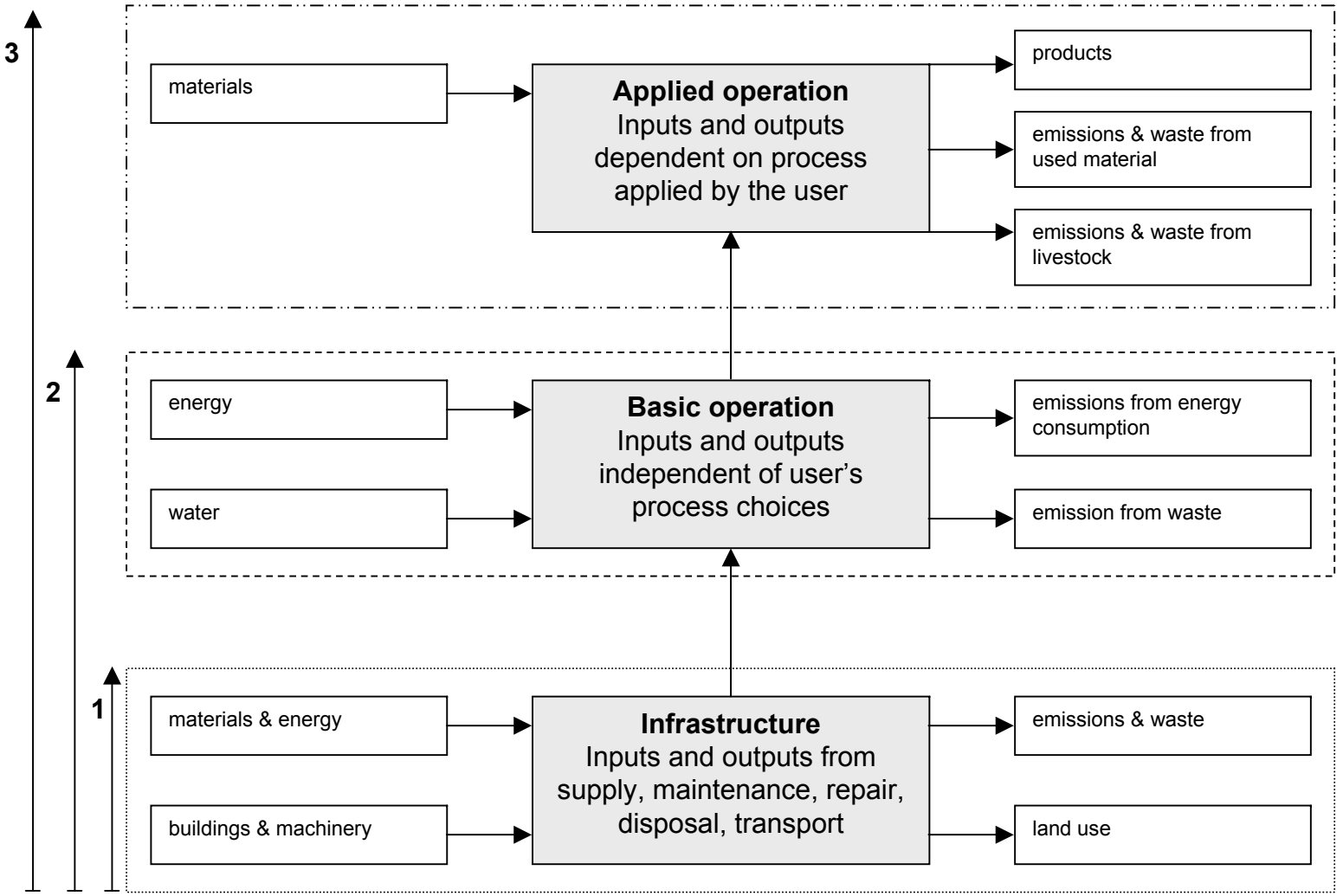
# Modelling of infrastructure and its operation

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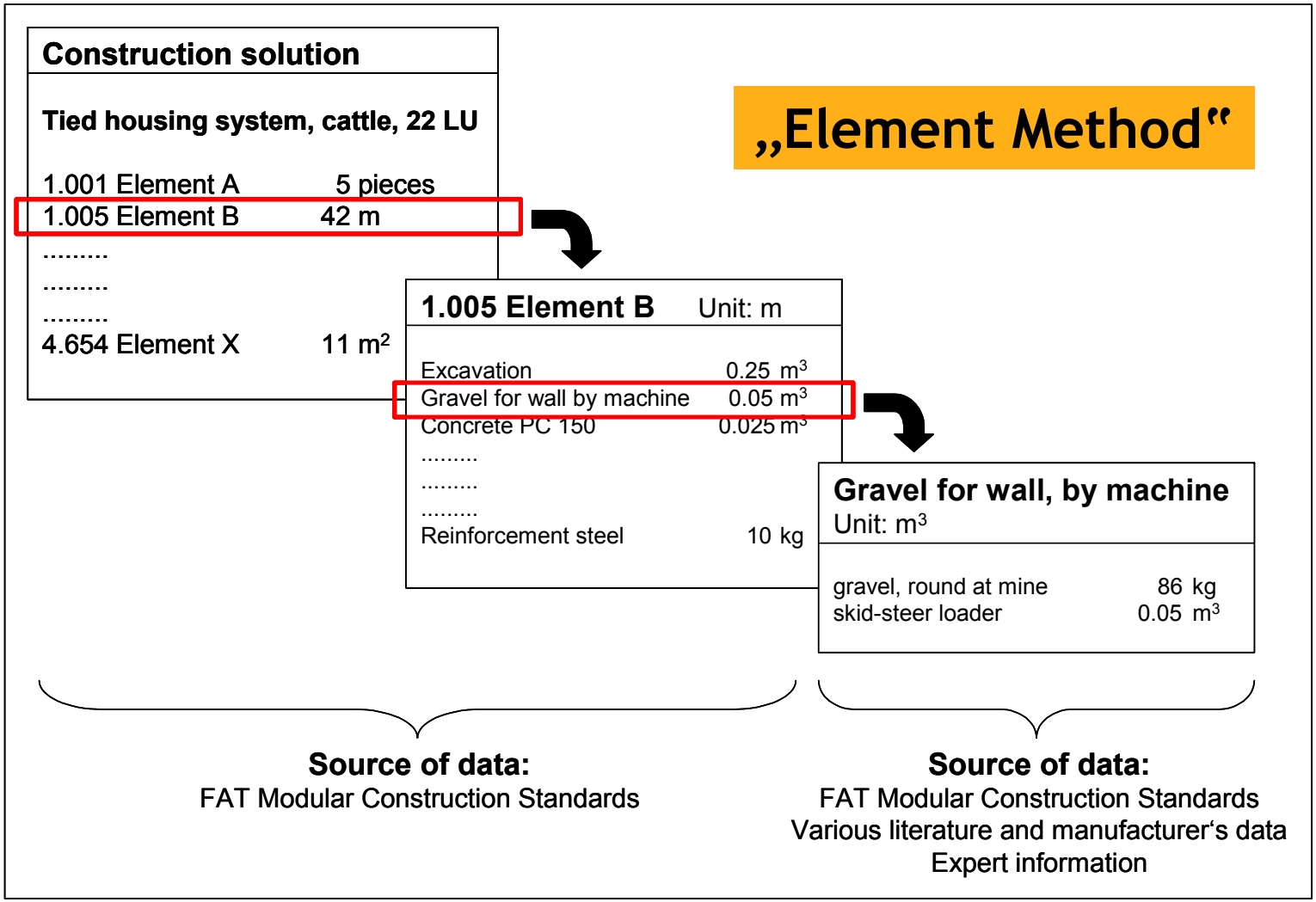
# Agricultural Buildings – Overview

- Infrastructure: construction, maintenance and disposal of typical agricultural buildings (e.g. construction materials and processes)
- Operation: operation of the buildings (e.g. energy demand, water, auxiliary means) included the supply of infrastructure

| # Infrastructure | # Operation | Category |
|---|---|---|
| 2 | 2 | Cattle housings |
| 2 | 2 | Pig housings |
| 1 | 0 | Tower silo |
| 3 | 3 | Dried roughage store |
| 2 | 1 | Manure storage |
| 1 | 0 | Shed |
| 1 | 1 | Milking parlour |

# Agricultural Buildings – Method

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# Agricultural Buildings — Results

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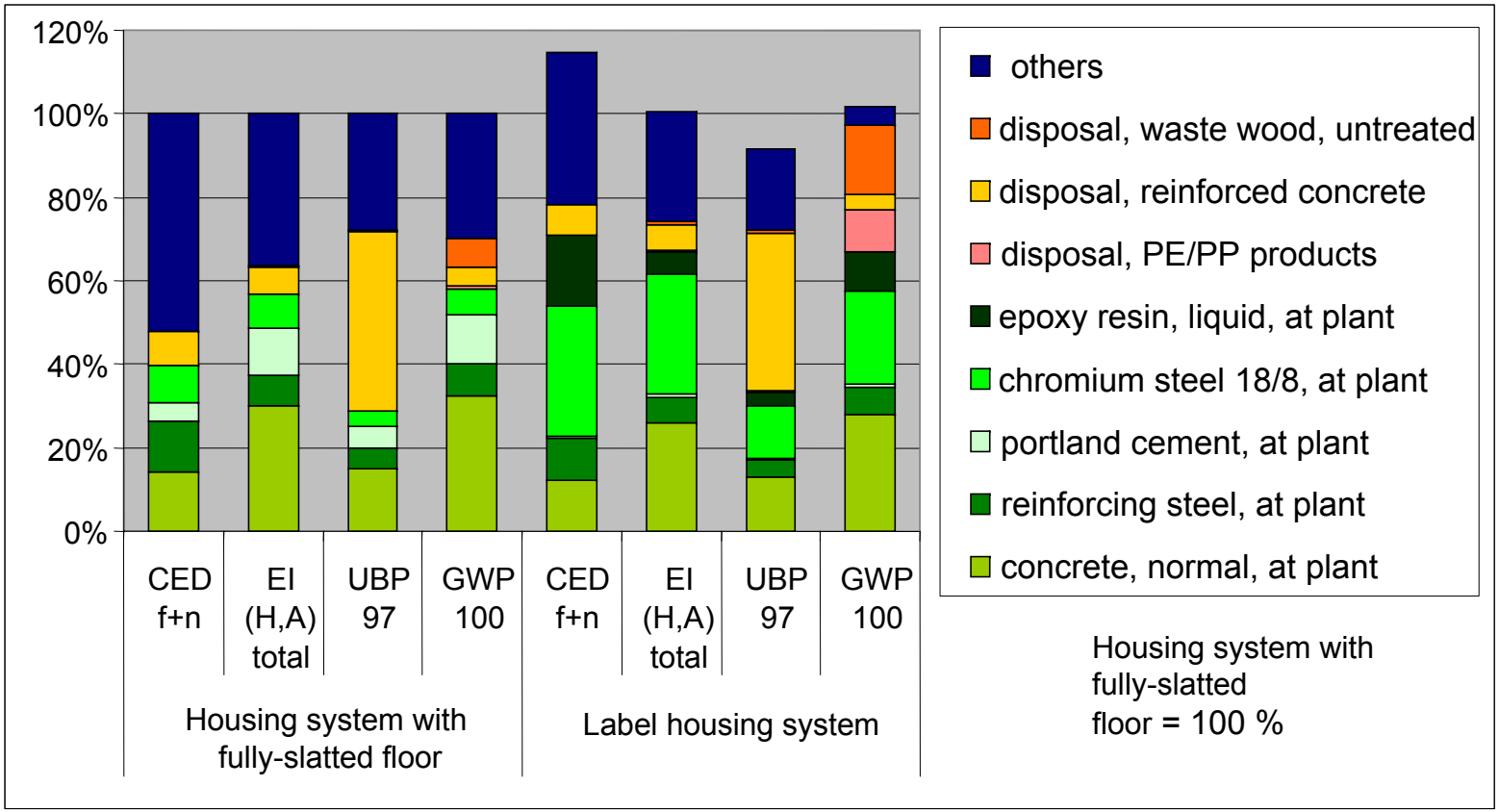
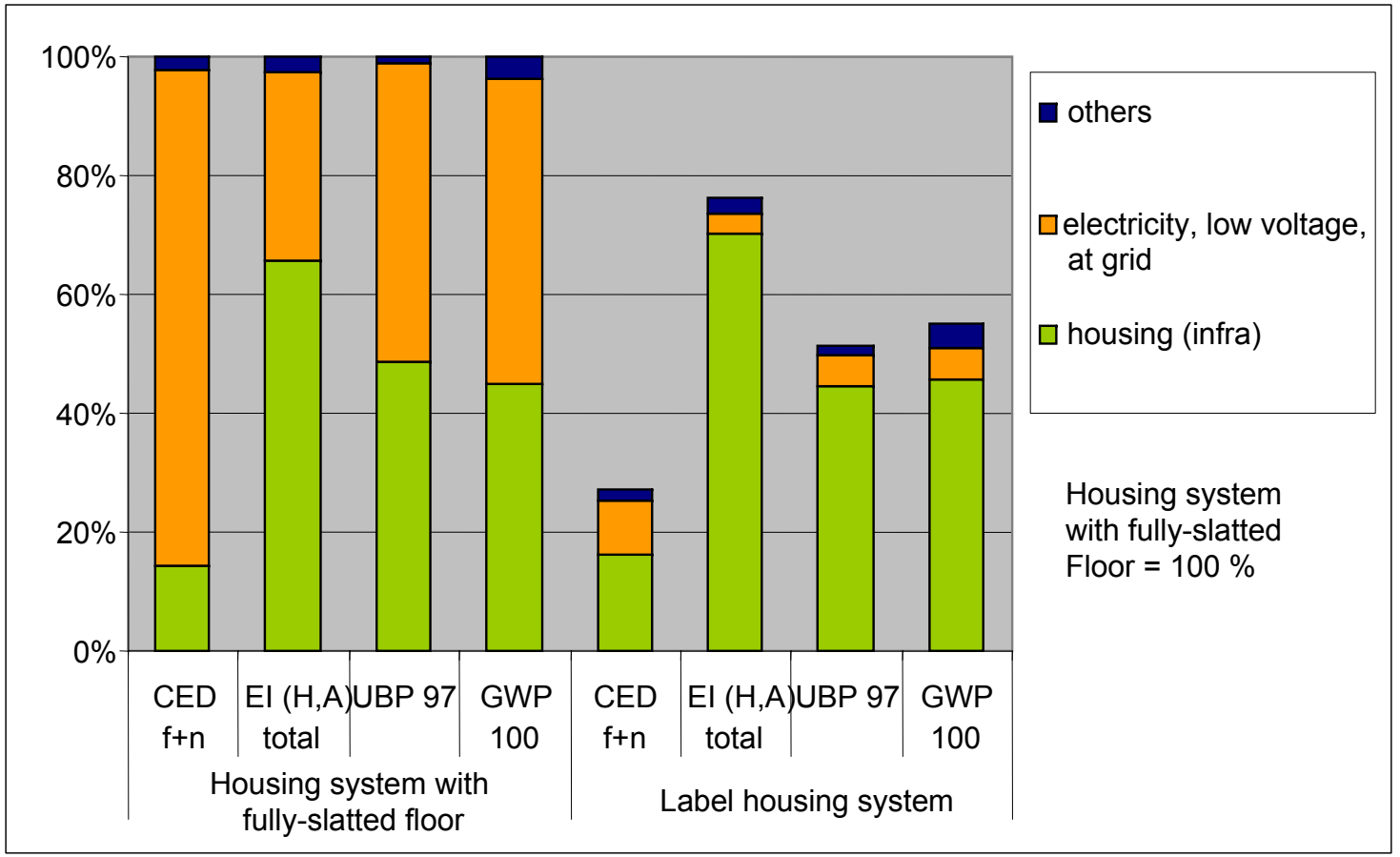
## Impact assessment of pig housing system - infrastructure



# Agricultural Buildings — Results

## Impact assessment of pig housing system - operation incl. infrastructure

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# Agricultural Machinery

- Manufacture, maintenance and disposal of tractors, other agricultural machinery and equipment
  - Agricultural machinery, general
  - Agricultural machinery, tillage
  - Trailer
  - Slurry tanker
  - Tractor
  - Harvester
- Data sources
  - Components, lifetime ⇨ estimation of experts, FAT
  - Fabrication, maintenance, disposal ⇨ literature

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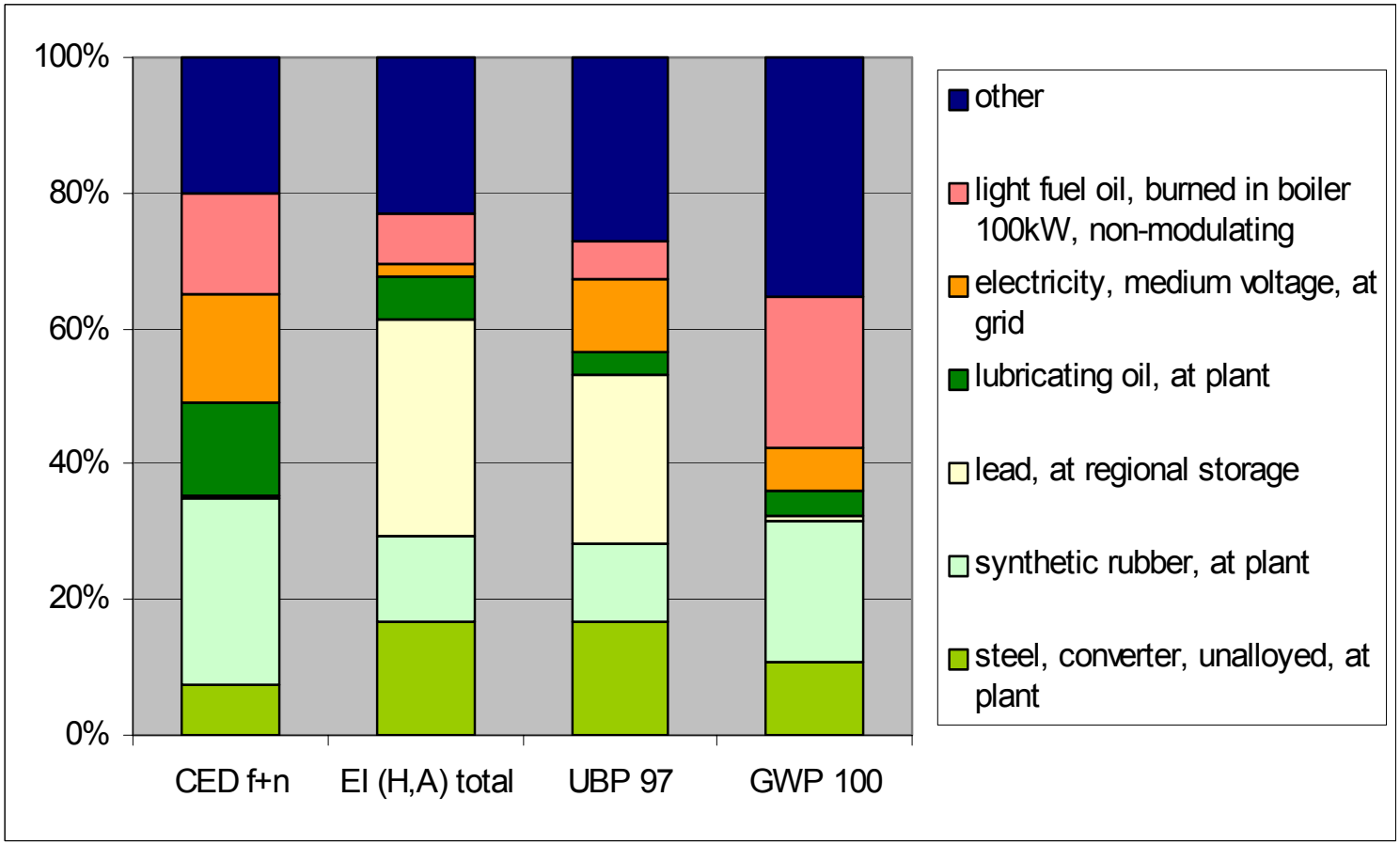
# Agricultural Machinery

Impact assessment for „tractor, production"

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# Drying of Agricultural Products

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- Drying of agricultural products in regional drying plants (infrastructure and energy use)
  - Grain drying, high temperature
  - Grain drying, low temperature
  - Grass drying ( ≠ hay drying)
  - Maize drying
- Data sources
  - Literature (energy use)
  - Associations of Swiss Drying Plants (infrastructure and energy use)

# Agricultural Field Work Processes

- Typical agricultural field work processes (use of fuel, emissions from combustion, demand of infrastructure)
- Data sources
  - Infrastructure ⇨ FAT-datasets „buildings" and „machines"
  - Working hours/-performance ⇨ Dept. Economics of Labor, FAT
  - Use of fuel ⇨ FAT measurements
  - NOx, CO and HC emissions ⇨ FAT measurements/models
  - other emissions ⇨ literature (SAEFL)

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# Agricultural Field Work Processes

| # | Activity |
|---|---|
| 9 | Tillage |
| 3 | Fertilisation |
| 3 | Sowing |
| 2 | Plant protection |
| 1 | Irrigation |
| 13 | Harvesting |
| 1 | Transport |
| Σ 32 | |

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# Agricultural Field Work Processes

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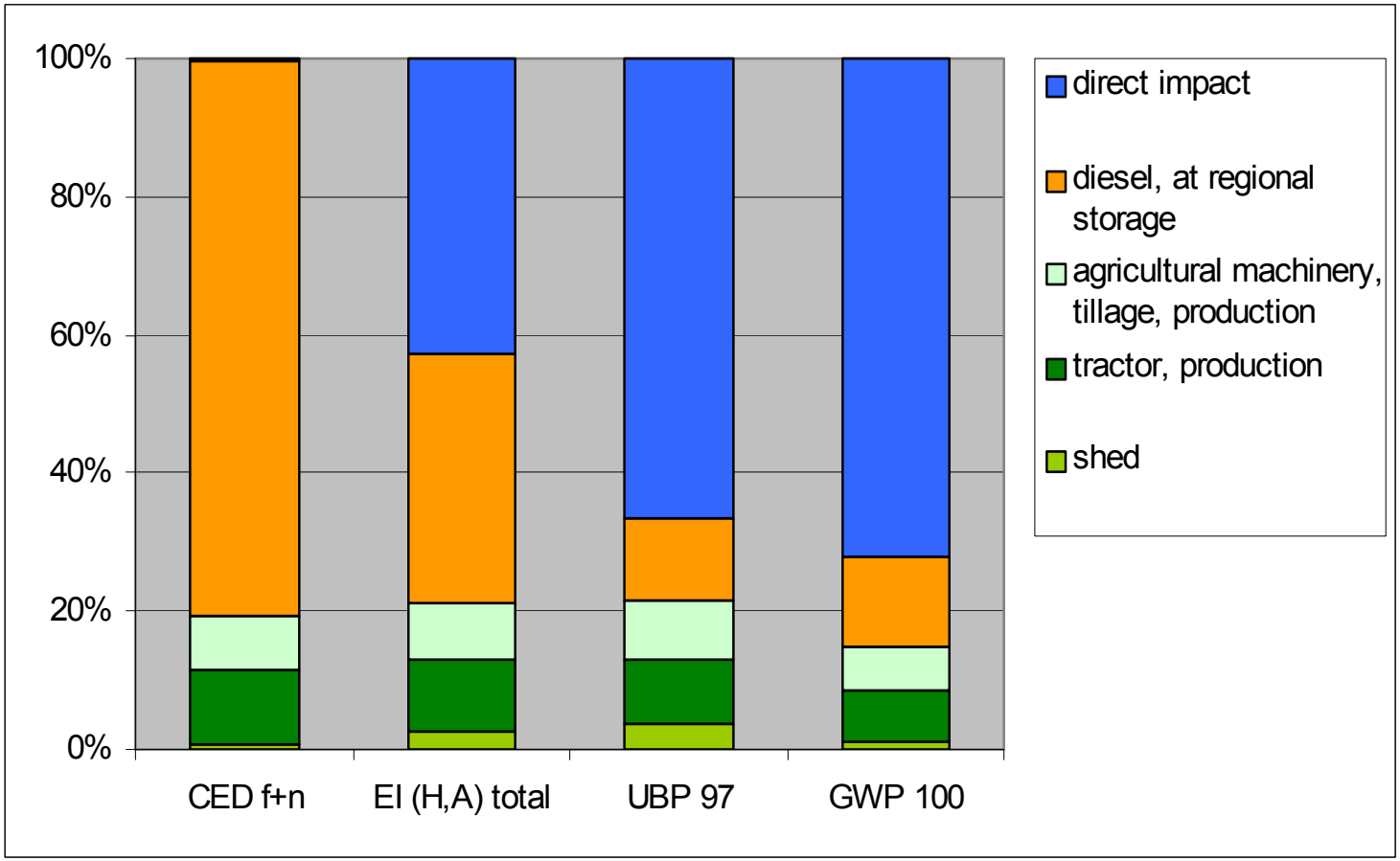
Environmental impacts „tillage, ploughing" (incl. infrastructure)



# Application

- LCAs of agricultural products
- Comparisons with LCAs of (agricultural) machinery
- …

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# Inputs from Industry
# Mineral Fertilisers

- The datasets refer always to the primary nutrients N, P and K
- Reference flows: kg N, kg $P_2O_5$, kg $K_2O$
- In case of multinutrient fertilisers (N-P, N-K): allocation to the primary nutrients
- Data from literature, partly from environmental reports
- Datasets for chemical compounds of fertilisers were compiled. Multinutrient-fertilisers can be calculated on this basis.

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# Inputs from Industry
# Fertilisers: Datasets

| | Name | LocalName | Loc. | Unit |
|---|---|---|---|---|
| **N-Dünger** | ammonium nitrate, as N, at regional storehouse | Ammoniumnitrat, als N, ab Regionallager | RER | kg N |
| | ammonium sulphate, as N, at regional storehouse | Ammoniumsulfat, als N, ab Regionallager | RER | kg N |
| | calcium ammonium nitrate, as N, at regional storehouse | Calciumammoniumnitrat, als N, ab Regionallager | RER | kg N |
| | calcium nitrate, as N, at regional storehouse | Calciumnitrat, als N, ab Regionallager | RER | kg N |
| | urea ammonium nitrate, as N, at regional storehouse | Harnstoff-Ammoniumnitrat, als N, ab Regionallager | RER | kg N |
| | urea, as N, at regional storehouse | Harnstoff, als N, ab Regionallager | RER | kg N |
| **P-Dünger** | single superphosphate, as P2O5, at regional storehouse | Singlesuperphosphat, als P2O5, ab Regionallager | RER | kg P2O5 |
| | triple superphosphate, as P2O5, at regional storehouse | Triple-Superphosphat, als P2O5, ab Regionallager | RER | kg P2O5 |
| | thomas meal, as P2O5, at regional storehouse | Thomasmehl, als P2O5, ab Regionallager | RER | kg P2O5 |
| **K-Dünger** | potassium chloride, as K2O, at regional storehouse | Kaliumchlorid, als K2O, ab Regionallager | RER | kg K2O |
| | potassium sulphate, as K2O, at regional storehouse | Kaliumsulfat, als K2O, ab Regionallager | RER | kg K2O |
| **NP-Dünger** | monoammonium phosphate, at regional storehouse | Monoammoniumphosphat, ab Regionallager | RER | kg |
| | monoammonium phosphate, as N, at regional storehouse | Monoammoniumphosphat, als N, ab Regionallager | RER | kg N |
| | monoammonium phosphate, as P2O5, at regional storehouse | Monoammoniumphosphat, als P2O5, ab Regionallager | RER | kg P2O5 |
| | diammonium phosphate, at regional storehouse | Diammoniumphosphat, ab Regionallager | RER | kg |
| | diammonium phosphate, as N, at regional storehouse | Diammoniumphosphat, als N, ab Regionallager | RER | kg N |
| | diammonium phosphate, as P2O5, at regional storehouse | Diammoniumphosphat, als P2O5, ab Regionallager | RER | kg P2O5 |
| | ammonium nitrate phosphate, at regional storehouse | Ammoniumnitratphosphat, ab Regionallager | RER | kg |
| | ammonium nitrate phosphate, as N, at regional storehouse | Ammoniumnitratphosphat, als N, ab Regionallager | RER | kg N |
| | ammonium nitrate phosphate, as P2O5, at regional storehouse | Ammoniumnitratphosphat, als P2O5, ab Regionallager | RER | kg P2O5 |
| **NK-Dünger** | potassium nitrate, at regional storehouse | Kaliumnitrat, ab Regionallager | RER | kg |
| | potassium nitrate, as N, at regional storehouse | Kaliumnitrat, als N, ab Regionallager | RER | kg N |
| | potassium nitrate, as K2O, at regional storehouse | Kaliumnitrat, als K2O, ab Regionallager | RER | kg K2O |
| **Ca-Dünger** | lime, algae, at regional storehouse | Kalk, Meeresalgen, ab Regionallager | CH | kg |
| | lime, from carbonation, at regional storehouse | Kalk, Carbonations-, ab Regionallager | CH | kg |
| | limestone, milled, loose, at plant | Kalkstein, gemahlen, lose, ab Werk | CH | kg |
| **Andere** | stone meal, at regional storehouse | Steinmehl, ab Regionallager | CH | kg |

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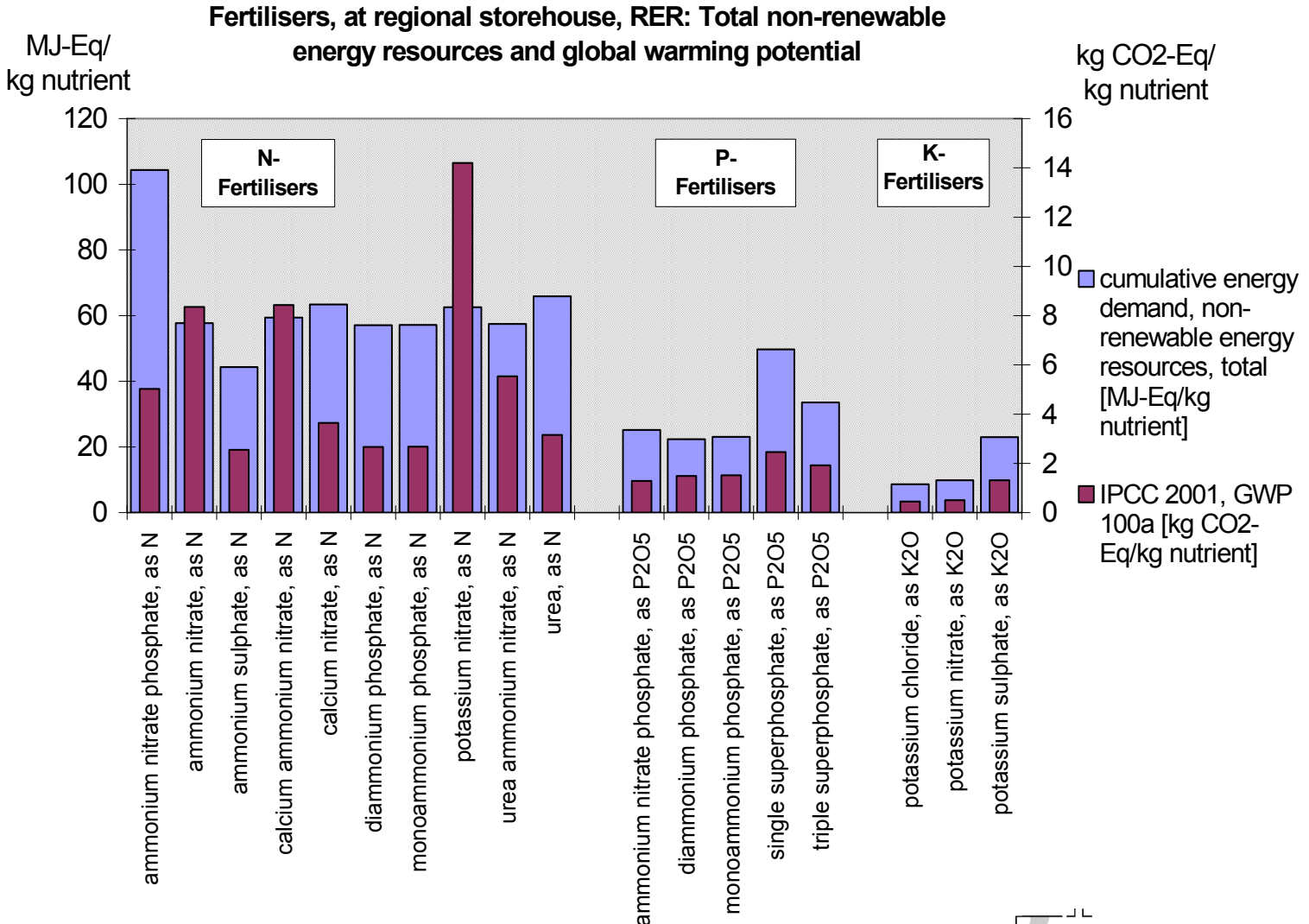
# Inputs from Industry
# Fertilisers: Results

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# Inputs from Industry
# Pesticides: Datasets

- Datasets for active substances and chemical classes (no commercial products)
- 19 classes of active substances
- 14 individual active substances
- 1 average dataset for all active substances
- In each case datasets defined for RER and CH (differences in energy and transport systems)

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# Inputs from Industry
# Pesticides: Data Quality

- Only rough estimations are possible, because:
  - Wide range of active substances (6'000 worldwide, 350 in CH)
  - Compounds are synthesised by complex chemical pathways
  - The production data are not public
- Based on a study from USA, 1987
- Estimations based on energy use
- The production of pesticides has only limited environmental impacts (compared to their use)
- The datasets are intended for calculating agricultural LCAs, but not for a comparison between different chemicals

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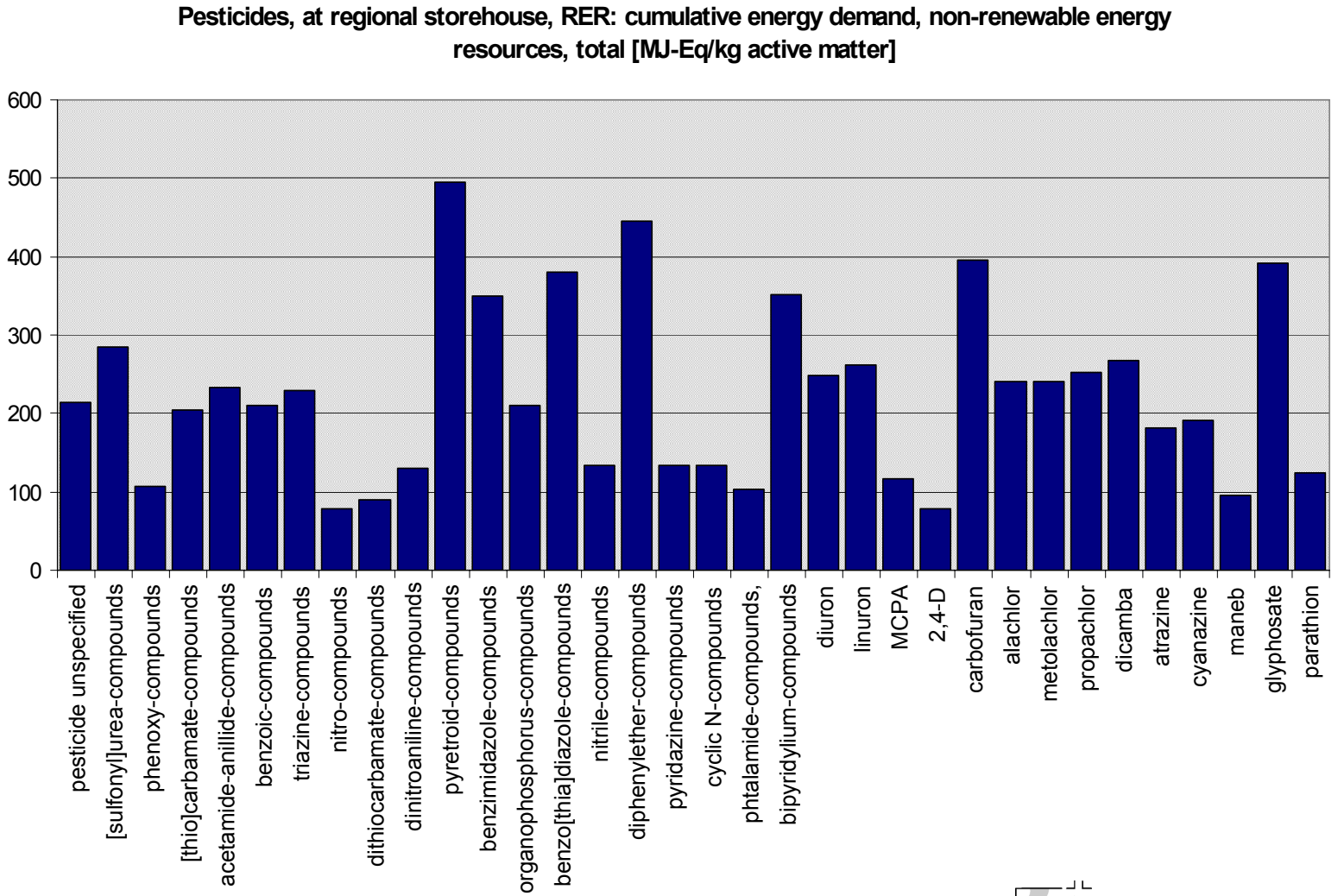
# Inputs from Industry
# Pesticides: Results

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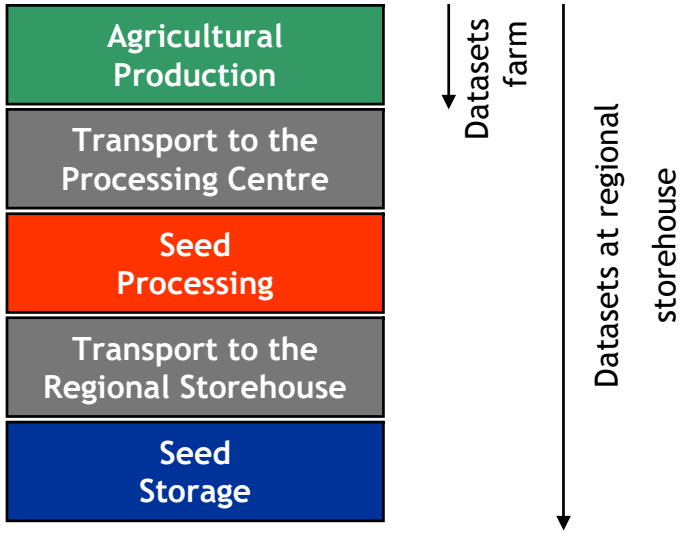
# Agricultural Inputs
# Seed

- Considered processes:




- Datasets for: cereals (wheat, barley, rye), potatoes, maize, rape seed, pea, sugar beet, grass and clover
- Datasets for integrated production (IP), in part also for organic production (Bio)

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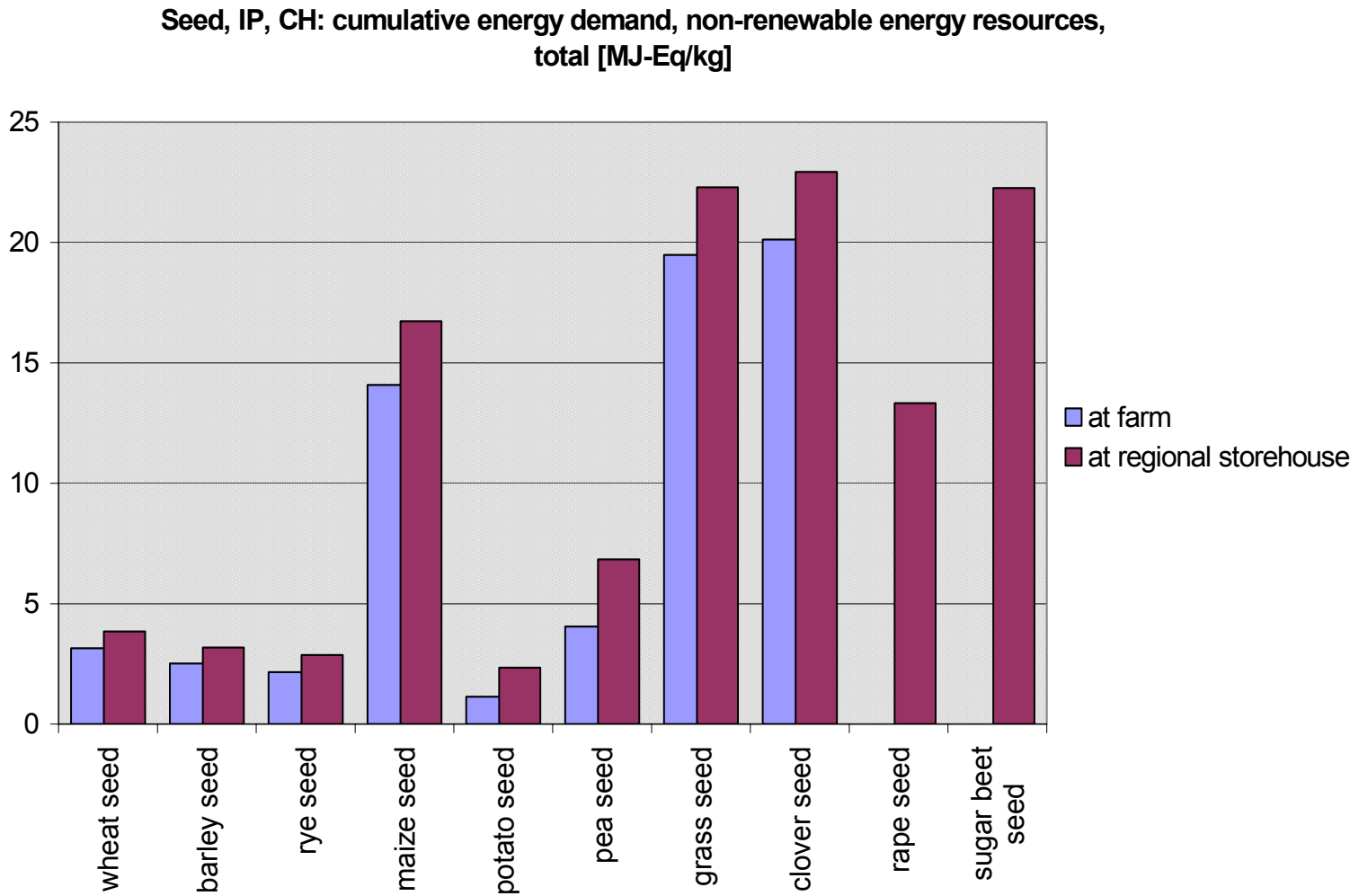
# Agricultural Inputs
# Seed: Cumulative Energy Demand

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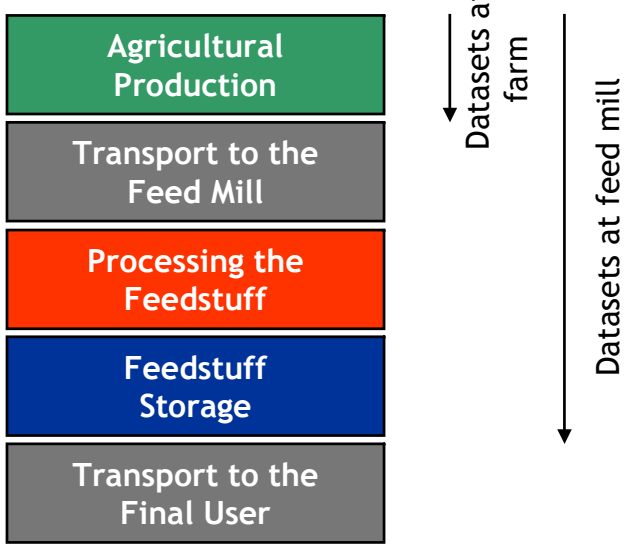
Agricultural Systems Presentation: T. Nemecek and S. Erzinger

# Agricultural Inputs Feedstuffs

- Considered processes:




- Datasets for: cereals (wheat, barley, rye), grain maize, protein peas and fava beans, and in addition soy bean meal, maize- and potato starch
- Datasets for integrated production (IP), partly also for organic production (Bio)

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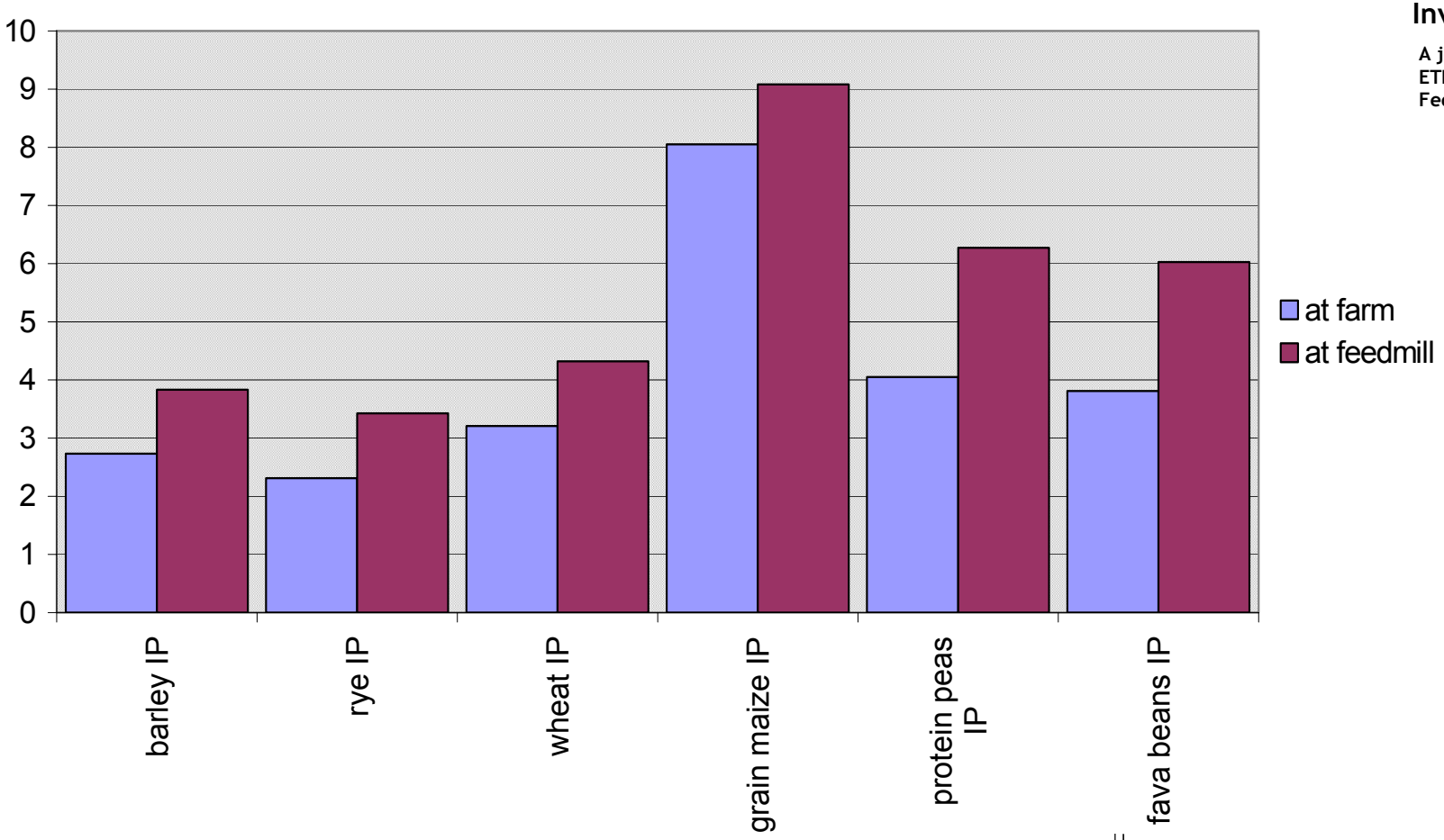
# Agricultural Inputs
# Feedstuffs: Results

**Feedstuffs, CH: cumulative energy demand, non-renewable energy resources, total [MJ-Eq/kg DM]**

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# Agricultural Products
# Arable Crop: Datasets

- 56 datasets for the most important products of arable crops: wheat, barley, rye, rape seed, sunflower, grain- and silage maize, potatoes, sugar- and fodder beets, fava- and soy beans, protein peas
- Valid for Swiss lowlands (largest part of Swiss arable land)
- Integrated production (IP) and organic production („Bio" or „organic")
- Integrated production of cereals and rape seed: differences between integrated intensive (IP) and extensive plant protection („Extenso" or „extensive")
- „Model crops": based on farm accountancy data, statistics, farms pilot networks, recommendations, documents from extension services, retailer surveys, expert knowledge

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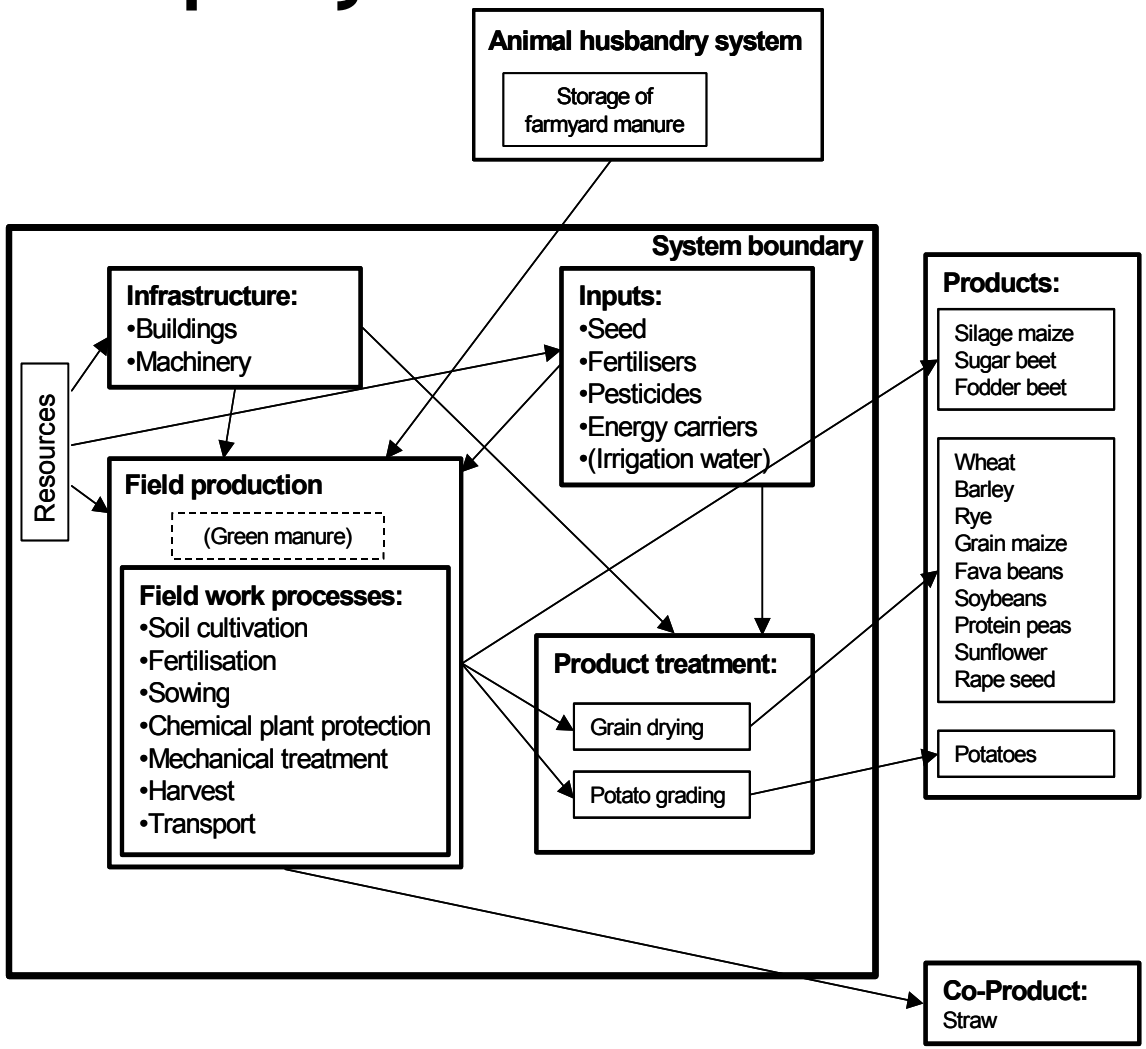
# Agricultural Products
# Arable Crop: System Boundaries

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# Agricultural Products
# Direct Field Emissions: N-Compounds

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- Emission coefficients depend on situation
- $NH_3$ in air: consideration of the fertiliser type, the application technique and the conditions during fertiliser application
- $NO_3$ in ground water: monthly balance between N-mineralisation and uptake by plants, under consideration of soil type, soil cultivation and fertilisation at unfavourable time
- $N_2O$ in air: adapted method according to IPCC, under consideration of indirect $N_2O$-Emissions

# Agricultural Products
# Direct Field Emissions: P-Compounds

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- 3 kinds of P-emissions in water:
  - run-off in rivers (solved $PO_4^{3-}$)
  - erosion in rivers (P bound to soil particles)
  - leaching in ground water (solved $PO_4^{3-}$)
- Emissions are dependent of:
  - Type of land use
  - Quantity of P-fertiliser
  - Kind of P-fertiliser (manure, compost, sewage sludge, mineral)
  - Field slope
  - Quantity of eroded soil

# Agricultural Products
# Direct Field Emissions: Heavy Metals


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- *Input-Output-Balance* (caused by farmer) per field
- Inputs:
  - Fertilisers (mineral and organic)
  - Seed
  - Pesticides
- Outputs:
  - exported primary products (e.g. grains)
  - exported co-products (e.g. straw)
- The final balance can be negative!

# Agricultural Products Direct Field Emissions: $CO_2$-Binding and Energy in Biomass

- $CO_2$-Fixation:
  - Determined on the basis of the amount of yield and C-content
  - Extraction of the resource „carbon dioxide, in air"
  - Negative greenhouse effects results for most of the agricultural products
- Energy in biomass:
  - Determined on the basis of the amount of yield and gross calorific value of the biomass
  - Only the energy in exported products and not the irradiated energy has been considered

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# Agricultural Products at Farm

## Correlation between CED and LCI results

| | CED fossil | CED nuclear | CO2 fossil | NMVOC | NOx | SO2 | PM2.5 | BOD, water | Cadmium, agric. Soil | Ammonia, air | Dinitrogen monoxide, air | Phosphorus, water | Nitrate, water |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CED fossil | 1.00 | 0.88 | 1.00 | 0.97 | 0.96 | 0.95 | 0.97 | 0.99 | 0.74 | 0.12 | 0.82 | 0.91 | 0.36 |
| CED nuclear | 0.88 | 1.00 | 0.89 | 0.83 | 0.78 | 0.79 | 0.79 | 0.89 | 0.59 | 0.17 | 0.68 | 0.74 | 0.36 |
| CO2 fossil | 1.00 | 0.89 | 1.00 | 0.98 | 0.96 | 0.95 | 0.97 | 1.00 | 0.75 | 0.13 | 0.83 | 0.92 | 0.37 |
| NMVOC | 0.97 | 0.83 | 0.98 | 1.00 | 0.99 | 0.96 | 0.99 | 0.99 | 0.78 | 0.17 | 0.88 | 0.97 | 0.41 |
| NOx | 0.96 | 0.78 | 0.96 | 0.99 | 1.00 | 0.95 | 1.00 | 0.97 | 0.78 | 0.17 | 0.91 | 0.97 | 0.45 |
| SO2 | 0.95 | 0.79 | 0.95 | 0.96 | 0.95 | 1.00 | 0.95 | 0.94 | 0.90 | -0.02 | 0.77 | 0.97 | 0.20 |
| PM2.5 | 0.97 | 0.79 | 0.97 | 0.99 | 1.00 | 0.95 | 1.00 | 0.98 | 0.77 | 0.18 | 0.88 | 0.96 | 0.40 |
| BOD, water | 0.99 | 0.89 | 1.00 | 0.99 | 0.97 | 0.94 | 0.98 | 1.00 | 0.73 | 0.17 | 0.86 | 0.92 | 0.43 |
| Cadmium, agric. Soil | 0.74 | 0.59 | 0.75 | 0.78 | 0.78 | 0.90 | 0.77 | 0.73 | 1.00 | -0.24 | 0.60 | 0.87 | 0.02 |
| Ammonia, air | 0.12 | 0.17 | 0.13 | 0.17 | 0.17 | -0.02 | 0.18 | 0.17 | -0.24 | 1.00 | 0.17 | 0.07 | 0.25 |
| Dinitrogen monoxide, air | 0.82 | 0.68 | 0.83 | 0.88 | 0.91 | 0.77 | 0.88 | 0.86 | 0.60 | 0.17 | 1.00 | 0.85 | 0.74 |
| Phosphorus, water | 0.91 | 0.74 | 0.92 | 0.97 | 0.97 | 0.97 | 0.96 | 0.92 | 0.87 | 0.07 | 0.85 | 1.00 | 0.33 |
| Nitrate, water | 0.36 | 0.36 | 0.37 | 0.41 | 0.45 | 0.20 | 0.40 | 0.43 | 0.02 | 0.25 | 0.74 | 0.33 | 1.00 |

Correlation coefficients:

- not significant
- significant <0.5
- significant 0.5-0.8
- significant 0.8-0.95
- significant >0.95

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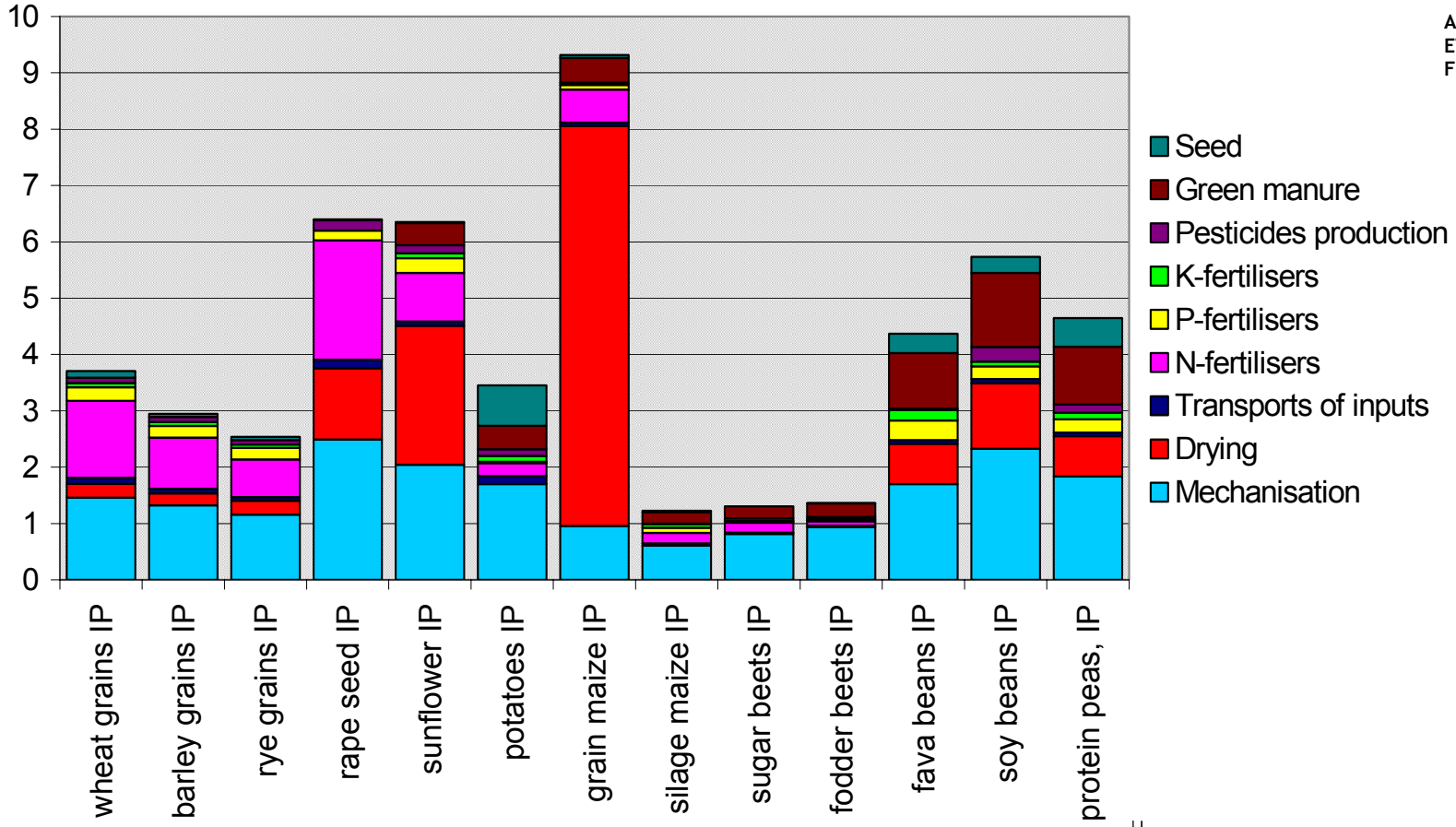
Agricultural Systems Presentation: T. Nemecek and S. Erzinger

# Agricultural Products
# Arable Crops: Energy Demand

**Arable crop products, at farm, CH: cumulative energy demand, non-renewable energy resources, total [MJ-Eq/kg DM]**

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ETH

EPF

PSI

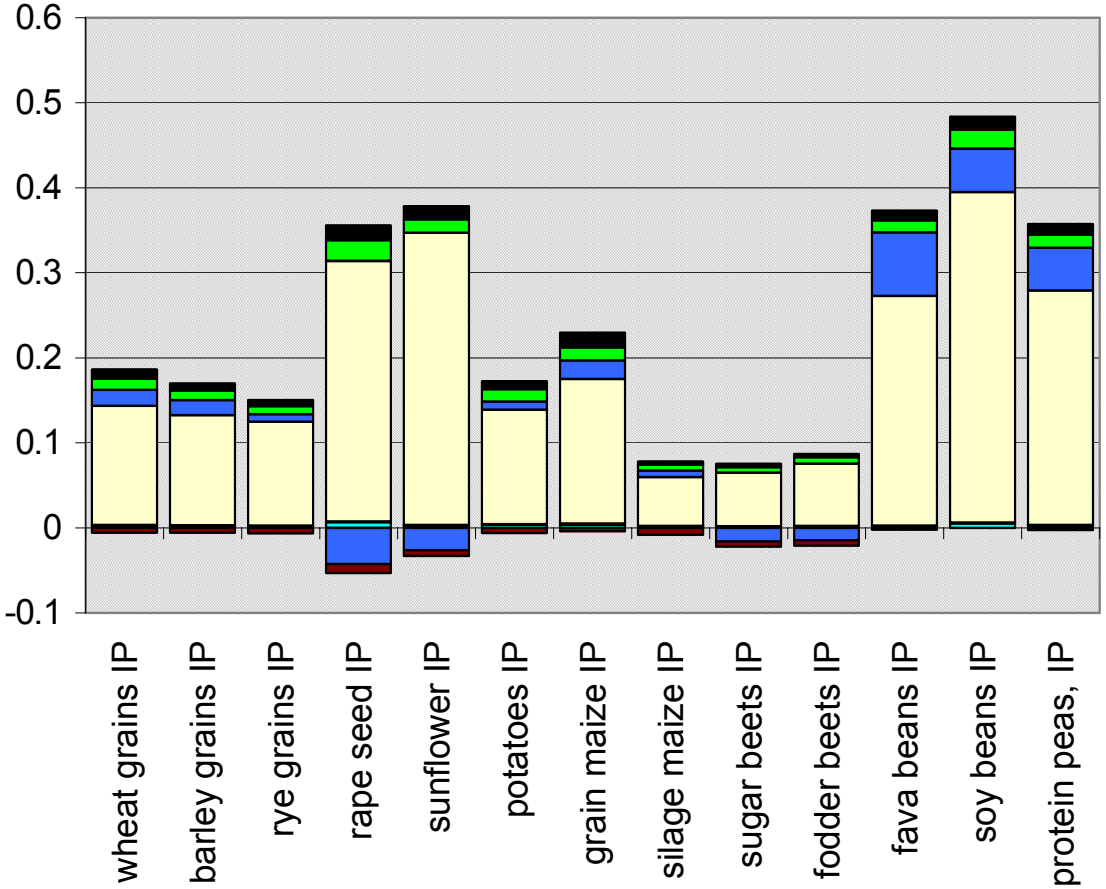
EMPA

EAWAG

FAL

# Agricultural Products
# Arable Crops: EcoIndicator 99

**Arable crop products, at farm, CH: eco-indicator 99 [points/kg DM]**

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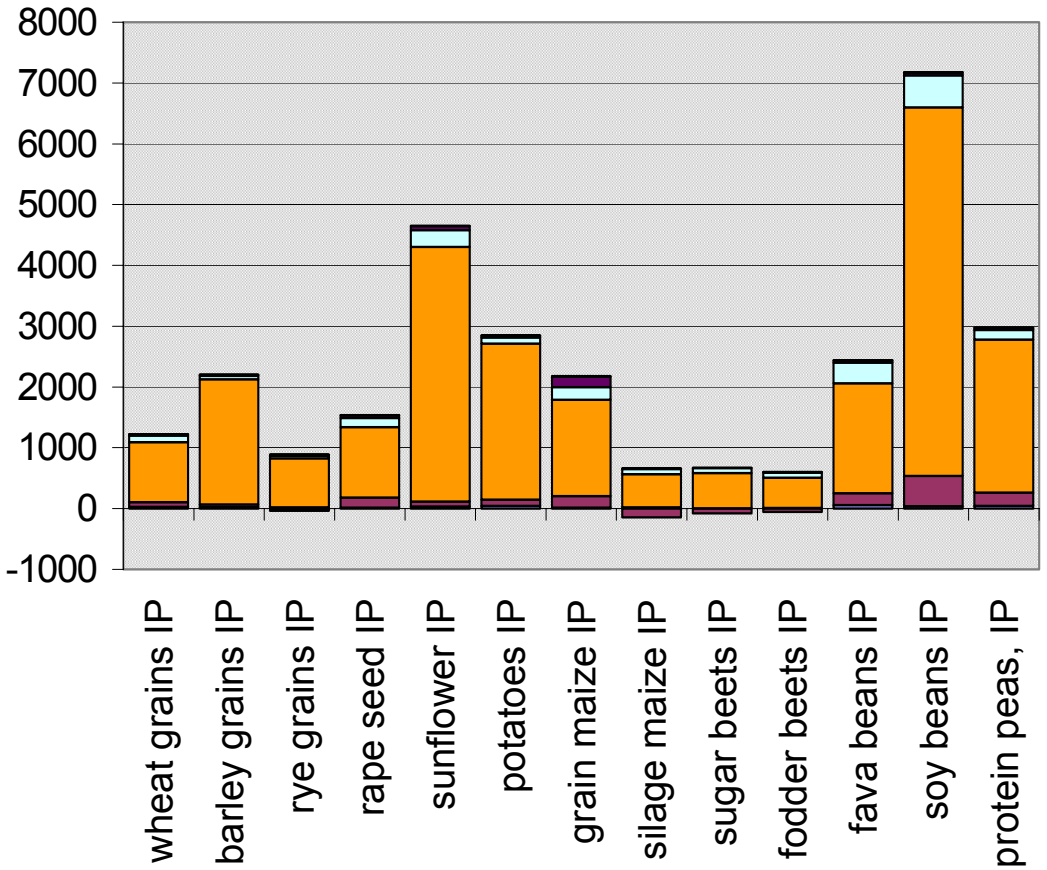
# Agricultural Products
# Arable Crops: UBP97

**Arable crop products, at farm, CH: ecological scarcity 1997 [UBP/kg DM]**

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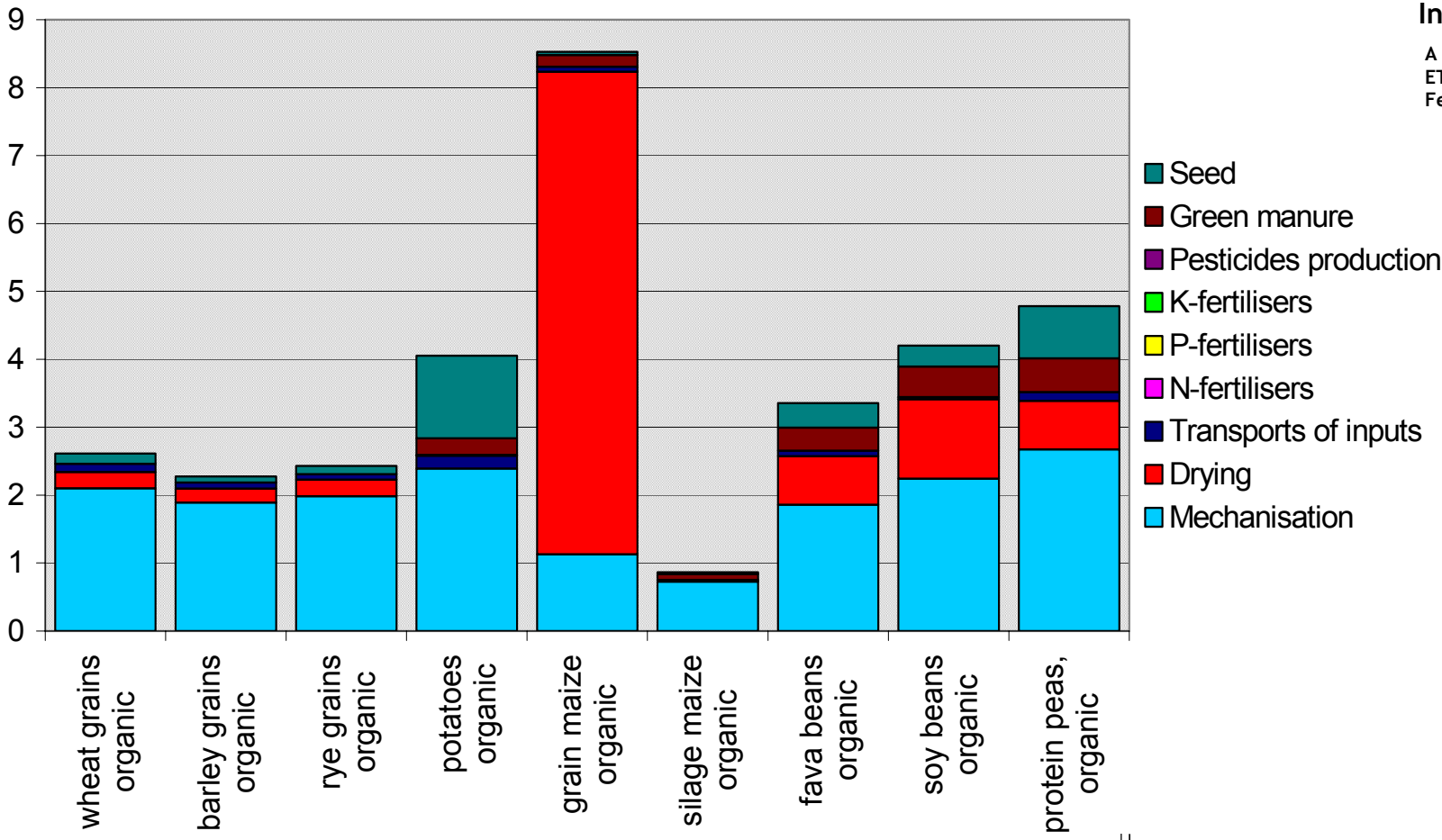
# Agricultural Products
# Arable Crops: Energy demand

**Arable crop products, organic, at farm, CH: cumulative energy demand, non-renewable energy resources [MJ-Eq/kg]**

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# Agricultural Products: Comparison between Farming Systems


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- The datasets are intended for analyses of process chains
- The datasets are **not** intended for comparisons between farming systems as such (IP and organic) → the system boundaries for individual fields are inappropriate for this comparison
  - Integrated and organic production are defined as systems at farm level
  - The different distribution of farmyard manure causes important differences in environmental impacts
  - Several environmental problems can only be studied in the context of the crop rotation (e.g. nitrate leaching)
  - Not all environmental impacts are considered in ecoinvent

# Agricultural Products
# Dried Roughage: Datasets

- 3 Datasets for dried roughage:
  - Hay intensive (IP): 5 cuts per year
  - Hay intensive (organic): 5 cuts per year
  - Hay extensive: 1 cut per year
- Permanent grasslands in Swiss lowlands
- Intensive production with cold-air drying
- Extensive production with field drying and baling

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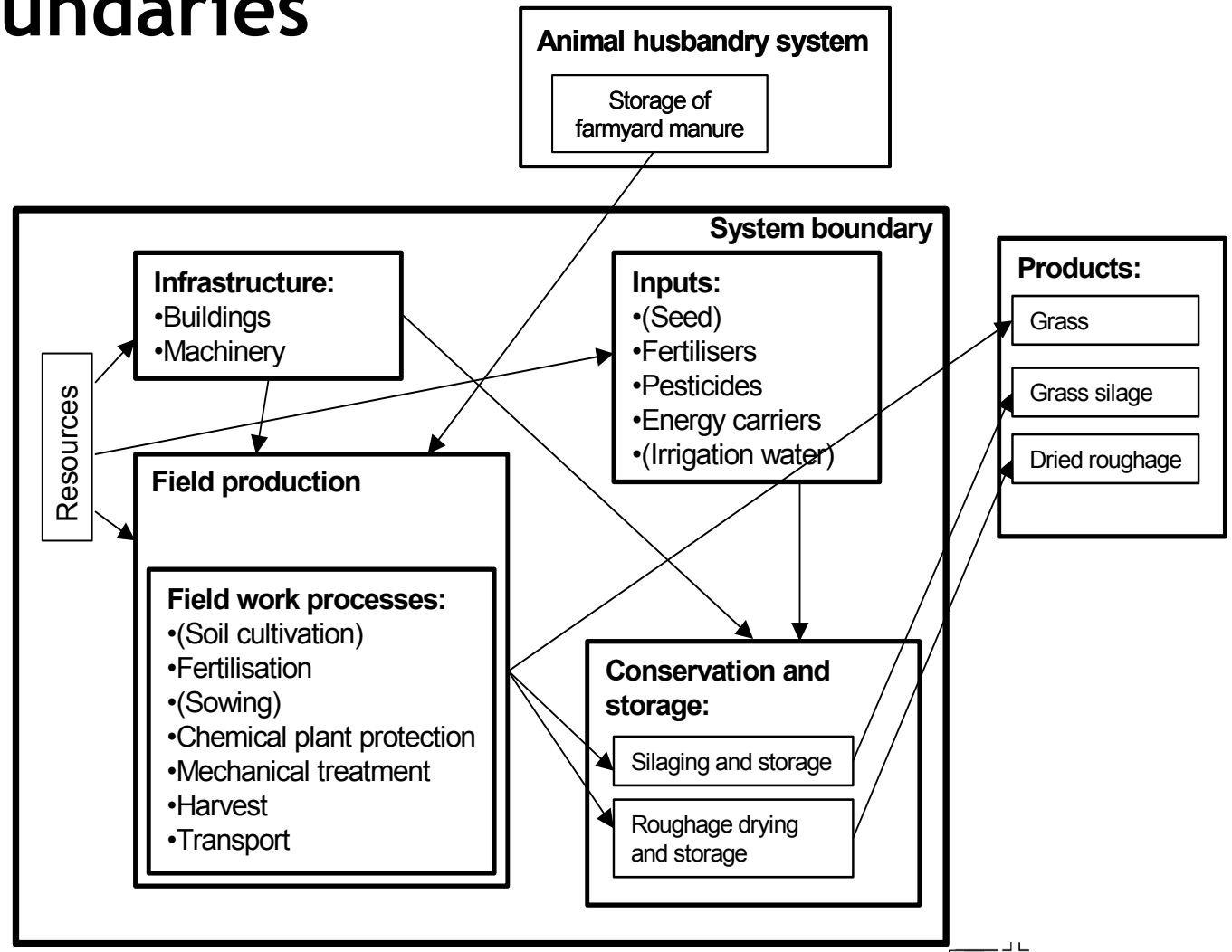
# Agricultural Products Dried Roughage: System Boundaries

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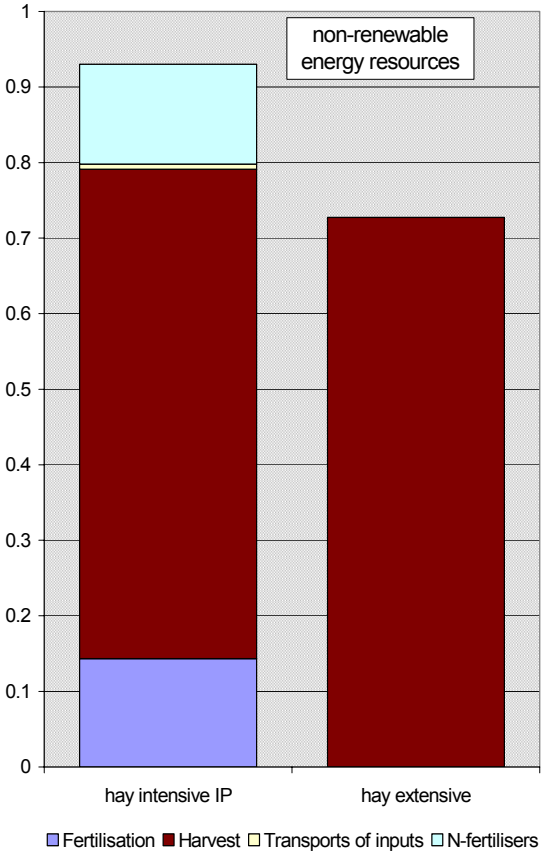
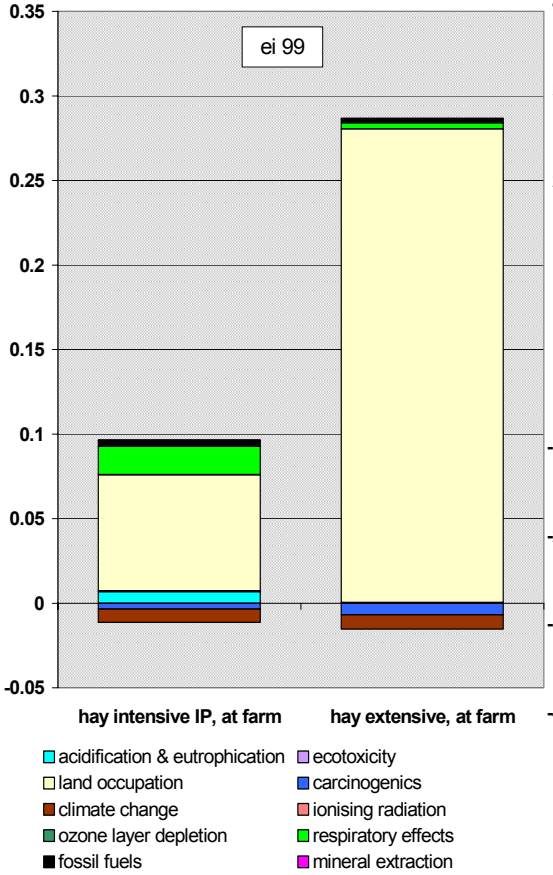
# Agricultural Products
# Dried Roughage: Results

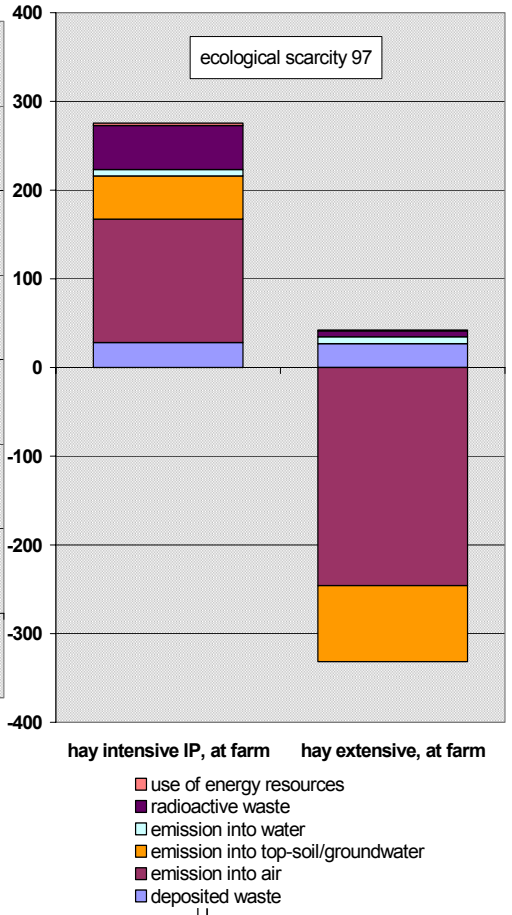
Hay, at farm, CH: cumulative energy demand, non-renewable energy resources, total [MJ-Eq/kg DM]




Hay, at farm, CH: eco-indicator 99, (H,A) [points/kg DM]




Hay, at farm, CH: ecological scarcity 1997 [UBP/kg DM]

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# Conclusions and Outlook

- Datasets in ecoinvent available for
  - Most important agricultural systems
  - Several agricultural products
- Further development of the methodology is necessary
  - Impact assessment → consideration of specific aspects of agriculture (e.g. pesticides)
  - Not considered environmental effects: biodiversity, soil quality
- Comparison and optimisation in LCA-studies

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