Horizon 2020 Programme
Research and Innovation Action

This project has received funding from the European Union's Horizon 2020 Research and Innovation Programme, under Grant Agreement ***No 773649****.*

Efficient Carbon, Nitrogen and Phosphorus cycling in the European Agri-food System and related up- and down-stream processes to mitigate emissions

Start date of project: 2018-09-01

Duration: 48 months

D5.1. Methodologies adapted for the environmental assessments for agro-ecosystems and of the food value chain

Deliverable details	
Deliverable number	*D5.1*
Revision number	*A1*
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Due date	0220
Delivered date	0220
Reviewed by	
Dissemination level	Public
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1. INTRODUCTION

1.1. Context and objectives

The European research project Circular Agronomics (Grant Agreement number: 773649) aims at contributing to a development towards sustainable, resilient and inclusive economies that are part of circular and zero-waste societies. In six European case study (CS) regions, a variety of different investigations and innovative production strategies are conducted to test their ability to meet the overall reduction goals of Circular Agronomics:

- Reduced nutrient surplus per agricultural area (-20% for N and P) and increased nutrient efficiency on a yield-scaled basis
- Reduced direct emissions to air and water (-10-15% for N) and reduced indirect emissions
- Increased net stabilizable carbon stocks in cropland by at least 0.04% per annum
- Reduction of carbon-and nutrient-rich waste (-10%)

Within this context, the innovative production strategies investigated in the CS will be evaluated for their environmental impacts in a Life Cycle Assessment (LCA) approach. This document describes the methodologies chosen for the environmental assessments of the investigated innovations.

1.2. Structure of the report

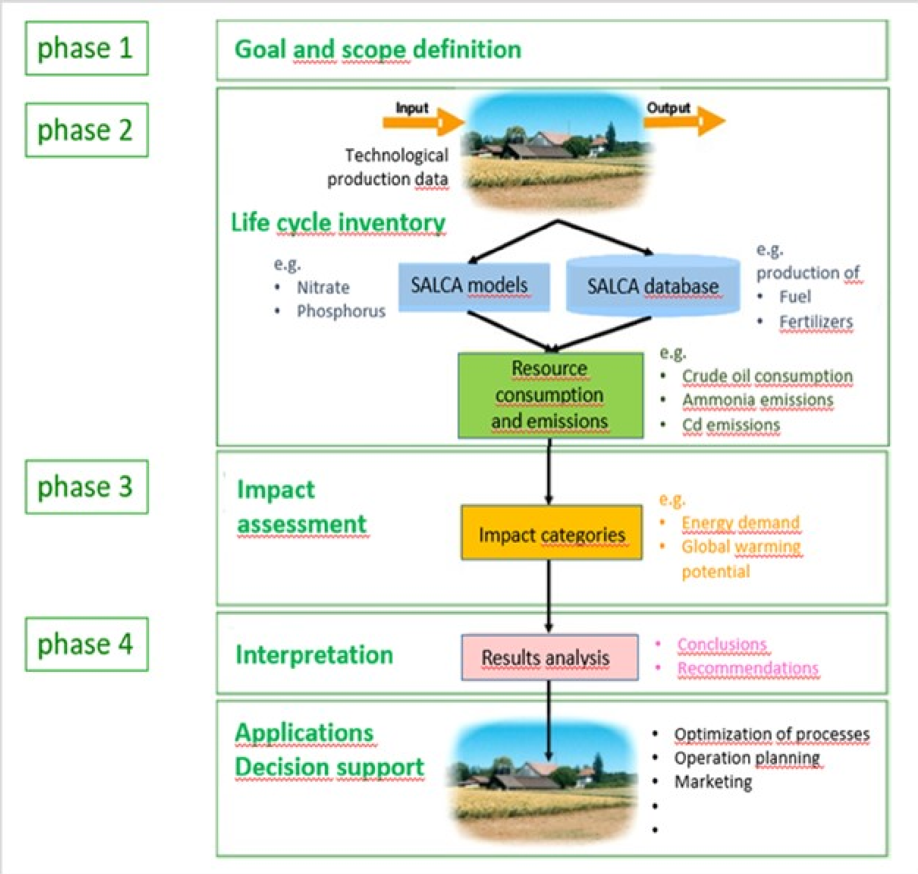
After an overall introduction in chapter 1, the general methodology of Life Cycle Assessment is described in chapter 2. This includes the description of the used methods and tools, as well as information that applies for all studied systems. Chapter 3 comprises the methodological approach, the interpretation concept and specific assumptions for the innovative production strategies assessed within the CS of Circular Agronomics. All studied systems are described in detail in the sub-chapters 3.3.1 – 3.3.10. Chapter 4 gives a brief overview over the further steps of the environmental assessment, including data collection and calculations.

2. METHODOLOGICAL APPROACH

2.1. Life cycle assessment

The method of environmental assessment or life cycle assessment (LCA) is used to examine a product or a production unit across its whole life cycle, from the cradle to the grave. All resources and emissions that may affect the environmental impacts are considered, quantified and evaluated, including raw material extraction, the production and usage of goods as well as disposal and reuse of waste materials. According to ISO 14040 (ISO, 2006a), the method of Life cycle assessment comprises 4 phases (Figure 1):

1. **Goal and scope definition**
   Mean features and assumptions of the assessment are defined, as for example the functional unit, system boundaries, data requirements and the considered impact categories.
2. **Life cycle inventory**
   This phase includes the collection and quantification of data. Inputs and outputs of the studied system are quantified and linked with emission models and life cycle inventories from databases. This results in the resource requirements and emissions (energy and substance flows) per functional unit of the investigated systems.
3. **Impact assessment**
   Results from the life cycle inventory are translated into different environmental impacts. Flows with similar environmental impacts are summarized in groups, the so-called impact categories (e.g. global warming potential, eutrophication, energy demand) which allows an interpretation of the results.
4. **Interpretation**
   In this last phase of the LCA, results from the life cycle inventory and impact assessment are interpreted in line with the goal of the study, conclusions are drawn and recommendations can be derived.



(Hersener et al. 2011, amended)

***Figure 1**: The 4 phases of life cycle assessment.*

2.1.1.SALCA

The environmental impact of the agronomic systems investigated in the case study regions of Germany (DE), Italy (IT), Spain (ES), The Netherlands (NL) and The Czech Republic (CZ) will be determined by Agroscope (AGRO), using SALCA (Swiss Agricultural Life Cycle Assessment). SALCA is the life cycle assessment method developed by Gaillard & Nemecek (2009). The method comprises a life cycle inventory database for agriculture, models for direct field and farm emissions, a selection of methods for impact assessment, calculation tools for farming systems (farm and crop level), and a concept for the evaluation and communication of the results.

2.1.2.FarmLife

The environmental impact of the strategy investigated in the case study region of Austria (AT) will be determined by the Agricultural Research and Education Centre Raumberg-Gumpenstein, AT (AREC). For this case study (CS), FarmLife, the life cycle assessment concept based on SALCA, will be used. For

FarmLife, the SALCA-Farm calculation tool and the emission models behind it were specifically adapted to Austrian conditions (Herndl, et al. 2015). The adjustments mainly concerned the emission models for direct emissions such as those of phosphorus, nitrate, heavy metals and animal emissions. New life cycle inventories on compound feed, mineral blends and viticulture were also implemented as part of the adjustment.

The major difference to SALCA is that FarmLife includes an additional concept for web-based data collection and result feedback for farmers (www.farmlife.at). With this concept, it is not only possible to calculate and show results of a farm life cycle assessment, but also to carry out strategic advice for environmentally friendly farm resources management. Based on general operating key figures, which are enriched with economic and ecological information, it is possible to identify fields of action or strengths and weaknesses in the handling of farm resources.

For the Austrian CS, the same impact categories as for the other CS will be applied (see chapter 2.1.1).

2.1.3. Calculation of technical sub-systems

LCI calculation (flows) for the respective subsystems containing technical innovation activities (e.g. separation and nutrient recovery units) in the case studies of ES, DE, IT, NL and CZ will be calculated by the Kompetenzzentrum Wasser Berlin, DE (KWB), using Umberto LCA+. Umberto LCA+ is a flow-modelling software linked to an LCA-database like ecoinvent. Specific flows (e.g. manure), sub-flows (e.g. biogas) and their fate during various treatment steps are estimated according to engineering standards and directly implemented into the software via scripts. Flows- or sub-flows (within the foreground system) can be linked with specific uses of external inputs, e.g. electricity or chemicals (background systems) to estimate environmental impacts. Within Circular Agronomics, this software is only used for the validation and calculation of the LCI as exemplary shown in Figure 2. The aggregated LCI results will be included into the LCA described in Chapter 2.1.1.

To simplify the work within data-exchange, the foreground-system under study is modelled in a so-called “sub-net”, while the “main-net” includes foreground and corresponding background data. In the Circular Agronomy Project, only the LCI of the “sub-net” is calculated to achieve results in an aggregated form (e.g. consumption of electricity per functional unit, instead of emissions and resource requirements for the specific electricity production). The latter example in Figure 2 shows a biogas plant, with respective input flows (manure) and output flows (digestate) expressed as Qa – volume, DM – dry matter, oDM – organic dry matter, TN – total nitrogen and TP – total phosphorus.

The sub-net considers a separated script for each treatment steps, e.g. generation of biogas in a biogas plant, as well as organic dry matter degradation, valorization of gas in a CHP (combined heat and power unit) into electricity and heat, and corresponding emissions. Corresponding aggregated input - output flows, emissions and consumables of the sub-net will be calculated, integrated into the LCA performed by AGROSCOPE (according to chapter 2.1.1).

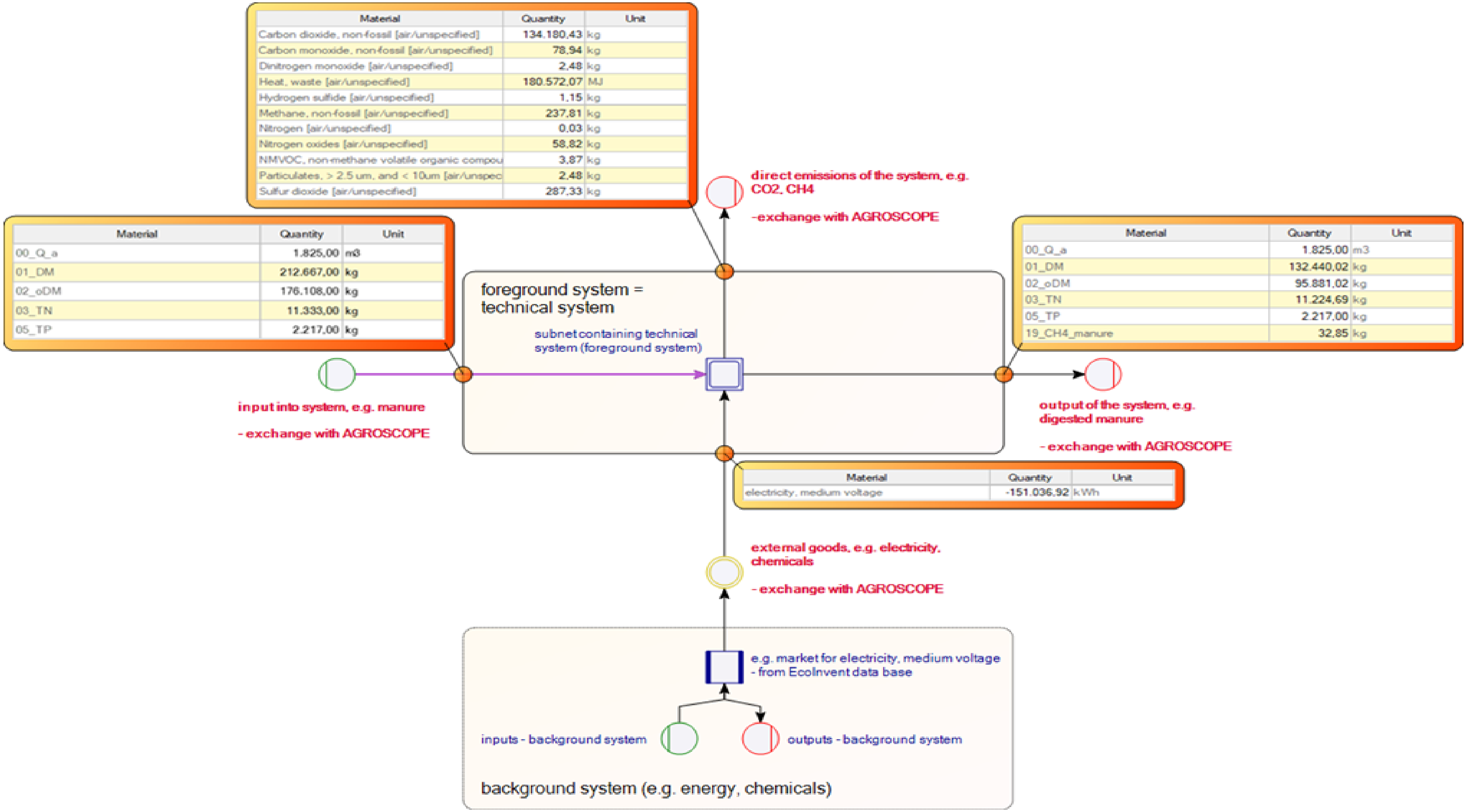


***Figure 2**: Exemplary flow-scheme of Umberto LCA + main-net with illustrated input and output flows.*

2.2. Life cycle inventory

For the calculation of upstream processes (e.g. the production of fertilizers, the construction of machinery), the respective life cycle inventories have to be integrated into the assessment. These life cycle inventories will be selected from different databases according to the following hierarchy: SALCA database (Nemecek et al., 2010), ecoinvent V3.6 (ecoinvent Centre, 2010), AGRIBALYSE® (Koch & Salou, 2013) (Table 1) and the European Life Cycle Database (ELCD) V3.2, based on their availability and suitability for the specific assessments.

The calculation of technical subsystems only includes the foreground system, and externalities (e.g. energy, chemicals) are shown in an aggregated way. Thus, the link between externalities and databases for calculation of emissions, resource use and corresponding impact categories will be done by AGROSCOPE.

The direct emission flows (ammonia, nitrate, nitrous oxide, methane, phosphorus and heavy metals) will be calculated according to the SALCA models with a parametrization specific for the countries in which the innovation takes place. For Austria, the models of FarmLife will be applied.

2.3. Life cycle impact assessment – impact categories and methods

A midpoint level approach will be conducted. The selection of impact categories includes the environmental impacts that are relevant for agronomic systems (see below). The full indicator set will be applied for a complete assessment of the case studies strategies (Table 1). For the interpretation and presentation of results, a reduced set of selected and aggregated indicators might be considered (Table 1).

Table 1: proposed LCIA impact categories and methods to be applied in Circular Agronomics, and suggested level of aggregation.

Impact category	Basic indicator set SALCA	Proposed for Circular Agronomics	Aggregation for Circular Agronomics
Non renewable energy resources (CED)	ecoinvent 2007	ecoinvent 2007	Exergy
Abiotic resource depletion	ILCD (CML 2001)	ILCD (CML 2001)	
Water stress index	AWARE	AWARE	
Land competition	CML 2001	CML 2001	
Deforestation	SALCA (LCI)		
Climate change	GWP100a (with climate change feedbacks, IPCC 2013)	GWP100a (with CC feedbacks, IPCC 2013)	GWP100a (with CC feedbacks, IPCC 2013)
Ozone formation	ILCD 2011	nc (high correlation with CED)	
Ozone depletion	ILCD 2011, Lane & Lant (2012)	nc (high correlation with GWP)	
Acidification	ILCD (Accumulated Exceedance)	ILCD (Accumulated Exceedance)	nc (high correlation with terr. Eutr.)
Eutrophication terr.	EDIP 2003 (GLO)	EDIP 2003 (GLO)	Normalised eutrophication (GLO)
Eutrophication aq. N	EDIP 2003 (GLO)	EDIP 2003 (GLO)	
Eutrophication aq. P	EDIP 2003 (GLO)	EDIP 2003 (GLO)	
Aquatic ecotoxicity	UseTox 2.0	UseTox 2.0	UseTox 2.0
Human toxicity	UseTox 2.0		
Biodiversity	SALCA		
Soil Quality	SALCA	To be verified	
Landscape aesthetics	SALCA		
		Proposed	
		Additional indicator	
		nc = not considered	

Non-renewable energy resources (MJ-Equivalents): The CED quantifies the demand for non-renewable energy resources (oil, coal and lignite, natural gas and uranium) using the upper heating or gross calorific value for fossil fuels according to Frischknecht et al. (2007).

Abiotic resource depletion: This impact category includes metal and mineral resources from CML 2001 (Guinée et al., 2001), which corresponds to the ILCD 2011 recommendation. The method characterizes current consumption and the available reserves and is therefore an indicator for the scarcity of metal and minerals. Phosphorus and Potassium are included in the mineral resources, while energy resources are not included in order to avoid overlaps with the CED.

Water stress index (WSI): The water stress index is calculated according to the method AWARE (Boulay et al., 2017).

Land competition: This method is taken from CML 2001. It calculates a sum of all land occupation flows (agri-cultural and non-agricultural uses). Water areas are not included by definition. It quantifies the land occupation irrespective of the type and quality of land use. It is recommended to distinguish agricultural from non-agricultural land use and within agricultural land at least arable land, intensive and extensive grassland.

Global warming potential (GWP): The characterization values for GWP (climate change) are taken from IPCC (2013). The values used are without climate-carbon feedbacks. Furthermore, biogenic CO_2 emissions and uptake of C during photosynthesis are considered. For CH_4, biogenic emissions have a lower carbon footprint than fossil CH_4 emissions, which accounts for the uptake of C in the biological processes.

Acidification: The method for the acidification potential follows the recommendation of ILCD 2011 (EC-JRC-IES, 2011), i.e. the method Accumulative Exceedance is used (Posch et al., 2008; Seppälä et al., 2006). The default method is denoted as "Acidification, GLO", which uses a European reference. It allows a geographical differentiation at country level. However, the current databases rarely provide data at this level of differentiation.

Eutrophication: The eutrophication potential (impact of the losses of N and P to aquatic and terrestrial ecosystems) is calculated according to the EDIP2003 method (Hauschild & Potting, 2005). It is differentiated for a European and a national (DE, AT, IT, ES, NL, CZ) situation. For studies, where most of the emissions are occurring in a given country, it is recommended to use the latter, otherwise to use the characterization factors for the European situation.

The method provides indicators for terrestrial eutrophication (dominated by NH_3, with contribution of NO_x), aquatic eutrophication N (dominated by NO_3, followed by NH_3 and NO_x) and aquatic eutrophication P (all emissions of P to water). For easier interpretation, these three categories are aggregated by normalization. The normalization factors are taken from Laurent et al. (2011). The values refer to the emission situation from the year 2004 (Table 2).

***Table 2**: Normalization values for EDIP 2003, based on Laurent et al. (2011).*

	Normalization value	Unit
Terrestrial Eutrophication	1.37E+03	m^2/person/year
Aquatic Eutrophication N	8.32E+00	kg Neq/person/year
Aquatic Eutrophication P	2.82E-01	kg Peq/person/year
Inverse value (normalisation value for SimaPro):		
Terrestrial Eutrophication	7.30E-04	person*year/m^2
Aquatic Eutrophication N	1.20E-01	person*year/kg Neq
Aquatic Eutrophication P	3.55E+00	person*year/kg Peq

Aquatic ecotoxicity: For aquatic ecotoxicity, the UseTox 2.0 method will be used (Rosenbaum et al., 2008).

General considerations and assumptions:

Deforestation will not be assessed in this project, as there is no major land use change included in the agronomic strategies assessed within the case studies. Human toxicity is not assessed in the innovative production strategies of the case studies and will therefore not be analyzed. Concerning soil quality, it has to be further analyzed for each CS, provided that it will directly be changed through the innovations and techniques applied on field. Concerning Acidification, there is a high correlation with terrestrial eutrophication, thus, an analysis of acidification might not be needed, if no additional information can be expected in comparison to terrestrial eutrophication.

2.4. Allocation procedure

Agricultural systems are often characterized by their multifunctionality, meaning that many processes contribute to the provision of more than one function, by yielding more than one product. Allocation describes the procedure where environmental impacts of inputs and processes are distributed among the different products that leave the studied system. Thus, it has to be determined, how inputs, processes and infrastructure are to be allocated to the different products (e.g. to wheat grain and straw). According to the ISO standard 14044 (ISO, 2006), allocation should be avoided whenever possible. This is the case, when an explicit assignment of inputs and outputs to a specific product is possible (e.g. milking machine → milk). If an explicit assignment to a single product is not possible, allocation should be based on physical criteria relevant for the product formation (e.g. yield, ha, livestock unit). This procedure makes sense, if the distribution between products is correlated with the criteria. Whenever an allocation based on physical criteria is not possible, monetary criteria should be used for the allocation, considering the gross output of the single products (amount * market price).

3. SPECIFIC METHODOLOGICAL APPROACH IN CIRCULAR AGRONOMICS

3.1. Interpretation concept – classification of Case Study strategies

There is a range of different experimental approaches conducted within the case studies (CS) and different study regions of Circular Agronomics. In order to get meaningful results and address the above-mentioned reduction goals of Circular Agronomics (chapter 1.1), environmental impacts will be evaluated for different production strategies instead of different study regions or CS. Thus, the experiments conducted in the different CS were grouped in innovative management – or production strategies (Figure 3, Table 3). As illustrated in Figure 3, each management strategy or production strategy is part of a bigger nutrient cycle and experiments often combine several strategies, thus cannot be considered completely isolated. However, this classification concept according to similar experimental approaches should allow to draw conclusions from the results within single production strategies.

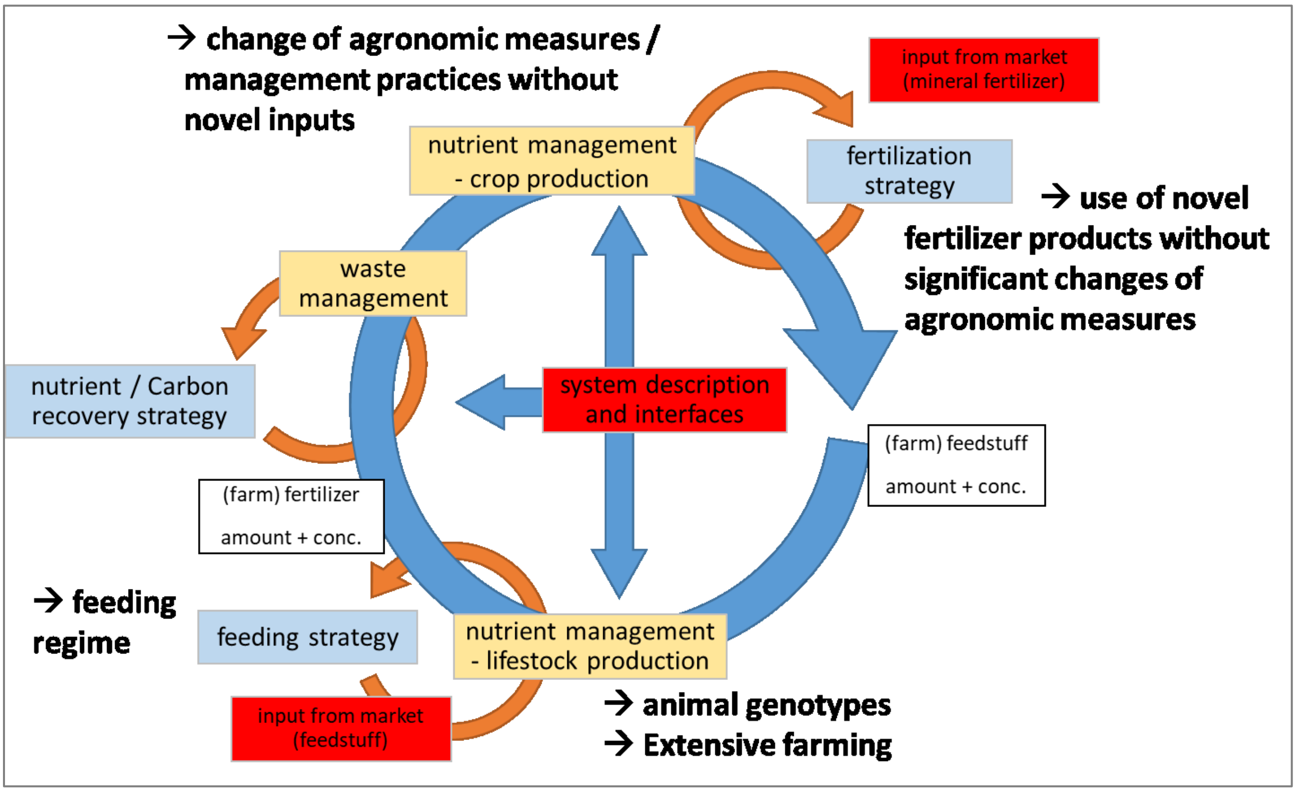


***Figure 3**: different management- and production strategies conducted within the case studies of Circular Agronomics.*

***Table 3**: classification of case studies experiments into management- / production strategies.*

Management-/ production strategy	**Assigned experiments (+ country code)**
Nutrient management in crop production	- Conservation tillage (IT) - Test of solar dried fertilizers in crop rotations (ES)
Fertilization strategy	- N use efficiency of winter wheat (DE / CZ) - Slurry application techniques (DE) - Fertigation with microfiltered digestate (IT) - Field test of novel PONDUS fertilizers (DE + NL) - Test of recovered NuReSys fertilizers (NL) - Acid whey application to soil (CZ)
Nutrient management in livestock production	- Fertilization of slurry from different feeding strategies (ES) - Extensive management and feeding strategy of cows (AT)
Feeding strategy	- Precision feeding of cows (ES)
Waste management	- Fertilizer production by solar drying (ES) - P fertilizer production from waste water (NuReSys) (NL)
Nutrient / Carbon recovery strategy	- Microfiltration of digestate (IT) - PONDUS fertilizer production (DE) - Acid whey separation (CZ)

3.2. Reference situation

The environmental impact of innovative management- or production strategies will be compared to conventional "business as usual" (BAU) practices in the specific study regions, which are defined individually for each experiment. The target audience of the results will primarily be local farmers and other stakeholders of the agri-food sector. Thus, the reference situation of each investigated production strategy was defined in agreement with the specific CSL, and consists of one particular management scenario conducted within the studied system, which is typical for local farmers of the study region.

3.3. System description of conducted experiments

The majority of experiments that are conducted within the study regions of the project are suitable for an environmental assessment. However, in some cases, an environmental assessment does not make sense. The selection of the below described scenarios (3.3.1 – 3.3.10) was made in agreement with the respective CSL to ensure a broad, but focused assessment.

Many of the conducted experiments are located on experimental farms and are scaled down to research plots or pilot plants, and do not reflect the final situation that might be implemented in practice. Thus, the experimental results need upscaling, which is a technical issue to ensure that the results are representative for realistic systems and respond to the research question. All agronomic data has to be extrapolated by the CSL. In the following section, all studied systems are described separately, reporting their function, functional unit, system boundaries, considered scenarios and reference, as well as the assigned allocation procedure and specific assumptions.

3.3.1. Nitrogen efficiency of winter wheat under different weather conditions (DE + CZ)

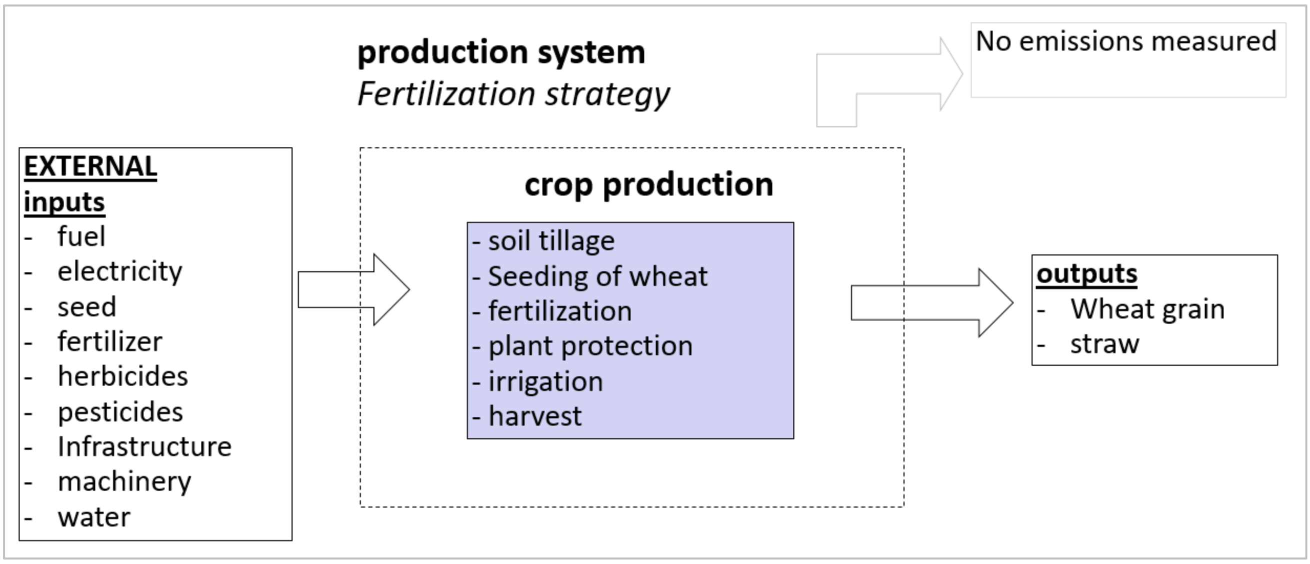


***Figure 4**: System under study – Nitrogen efficiency of winter wheat under different weather conditions – conducted in DE and CZ.*

System and its function: FERTILIZATION STRATEGY

Different genotypes of winter wheat are tested for their Nitrogen use efficiency (NUE) when supplied with different amounts of mineral N fertilization, in 3 different weather situations (Figure 4). Several different wheat varieties are tested in the experiment, however, for environmental evaluation, a selection of three genotypes will be assessed (one cultivar with a high / medium / low NUE, respectively). The final selection of the considered cultivars will be made by the CSL, if possible, only after the experiment will have been finished. There are five different levels of N fertilization (0 N, 50% N, 75% N, 100% N, 125% N) and three different weather conditions (non-irrigated in Germany, irrigated in Germany, non-irrigated in the Czech Republic) (Figure 5). The function of the system lies in the production of wheat grain, with two main outputs: wheat grain (main product) and wheat straw (co-product).

System boundaries: Field level. From the harvest of pre-crop until harvest of wheat. (Pre crops: seed-wheat (DE) and maize grain (CZ)).

Functional unit: 1 Mg of wheat grain (86% Dry Matter, protein content or given protein yield).

Allocation:

- Germany: no allocation (100% straw remains on the field)
- CZ: 50% of the straw remains on the field, 50% is used externally as animal bedding. No allocation for the straw that remains on the field, allocation based on monetary criteria for the part of the straw that is used externally.

Reference: 100% N fertilization for 3 genotypes, non-irrigated conditions in DE and CZ (= BAU in DE and CZ).

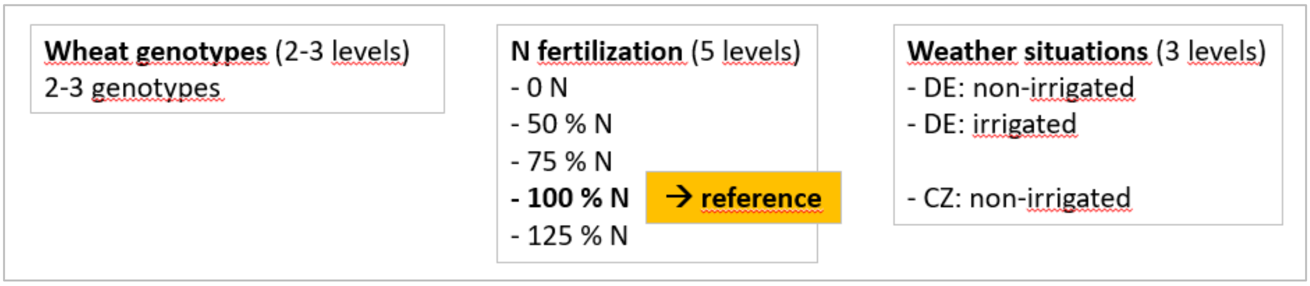


Figure 5: Considered scenarios and reference for the system under study – Nitrogen efficiency of winter wheat under different weather conditions – conducted in DE and CZ.

3.3.2. Different slurry application techniques and nitrification inhibitors to reduce field gas emissions (DE)

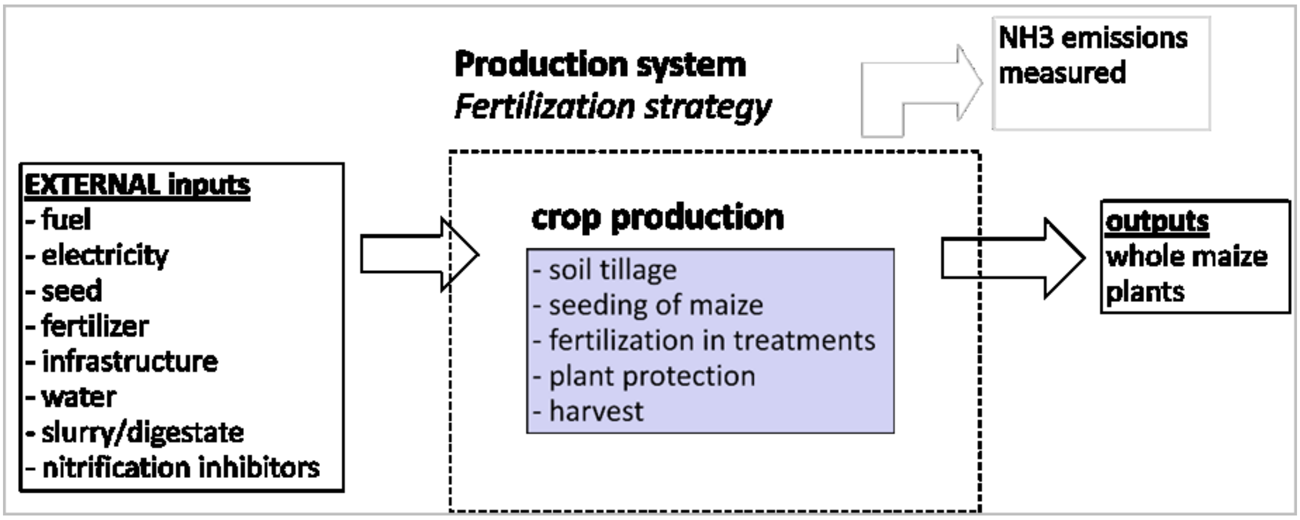


Figure 6: System under study - Different slurry application techniques and nitrification inhibitors to reduce field gas emissions – conducted in DE.

System and its function: FERTILIZATION STRATEGY

Different slurry application techniques are tested in combination with nitrification inhibitors (NI) on a field experiment with maize, to reduce field NH_3 emissions (Figure 6). There are three levels of application techniques (broad spread + incorporation, placing "under feet", placing between rows) and three levels of different application times (four weeks before sowing, one day before sowing, four weeks after sowing (the latter combined only with broad spread application)). All application times and techniques are combined with three levels of NI (no NI, the NI containing product PIADIN® and the NI substance DMPSA (3,4-DIMETHYLPYRAZOLE-SUCCINIC ACID)) (Figure 7).

System boundaries: Field level. From the harvest of pre-crop (oats, 2018) until harvest of maize.

Functional unit: 1 Mg of whole maize plants (dry matter)

Allocation: No allocation. Whole maize plants are harvested for biogas production.

Reference: Separately for each application time:

- Broad spread application without NI, 4 weeks before sowing
- Broad spread application without NI, 1 day before sowing
- Broad spread application without NI, 4 weeks after sowing

Then: comparison of different application times (= important factor to determine maize yield).

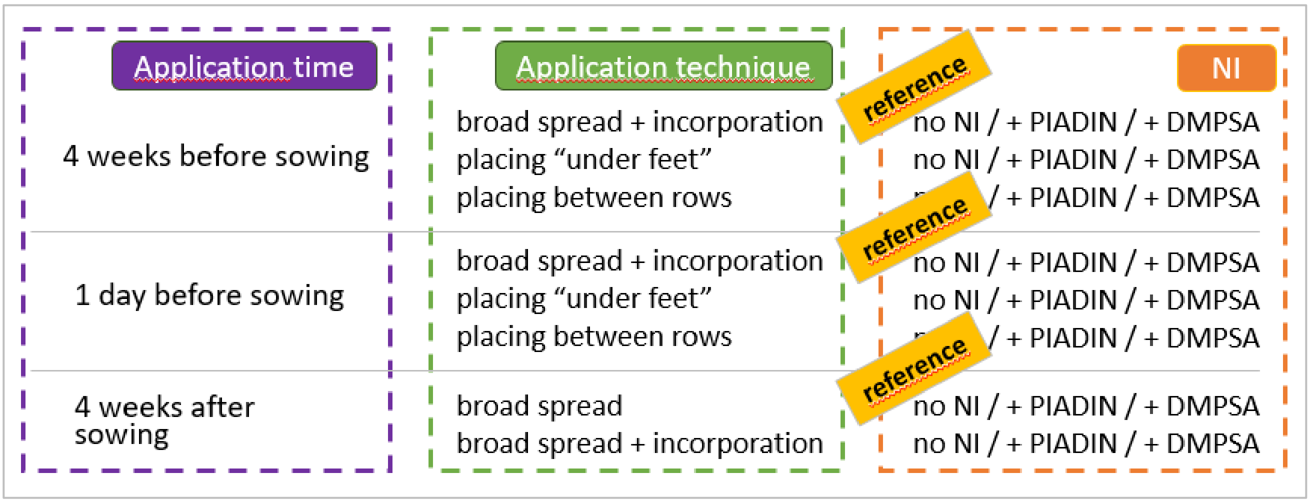


Figure 7: *Considered scenarios and reference for the system under study - Different slurry application techniques and nitrification inhibitors to reduce field gas emissions – conducted in DE.*

3.3.3. Conservation tillage to increase water- and nutrient use efficiency and its effect on soil quality characteristics (IT)

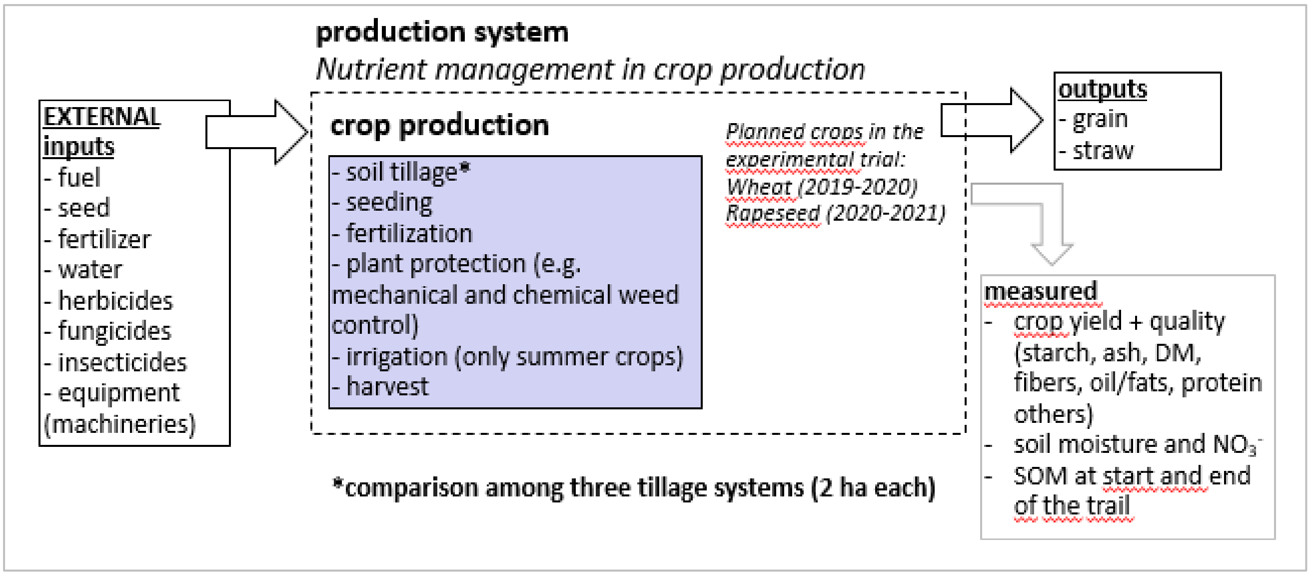


Figure 8: *System under study – Conservation tillage to increase water- and nutrient use efficiency and its effect on soil quality characteristics – conducted in IT.*

System and its function: NUTRIENT AND CARBON MANAGEMENT IN CROP PRODUCTION

Three different tillage systems are compared for their effects on yield and quality of crops in a wheat – rapeseed rotation on water- and nutrient use efficiency and on soil quality characteristics (Figure 8). The three tillage systems comprise the BAU treatment conventional tillage (30-35 cm plowing, harrowing and hoeing), minimum tillage (15-20 cm harrowing and hoeing) and no-tillage (direct seeding on residues of previous crops) (Figure 9). The experiment is conducted under farming conditions on 2 ha area for each tested tillage system. Before the field experiment started, there was a four-year period of no-tillage on all fields.

System boundaries: Field level. From the harvest of pre-crop (maize, 2019) until harvest of wheat (2020) and rapeseed (2021).

Functional unit: 1 Mg of crop yield (wheat / rapeseed).

Allocation: Depending on the tillage system:

Conventional tillage: Allocation based on monetary criteria for wheat straw (used externally as animal bedding). No allocation for rapeseed straw (remains on the field).

Minimum / no-tillage: No allocation. All straw remains on the field.

Reference: Conventional tillage (= BAU: 30-35 cm plowing, harrowing and hoeing).

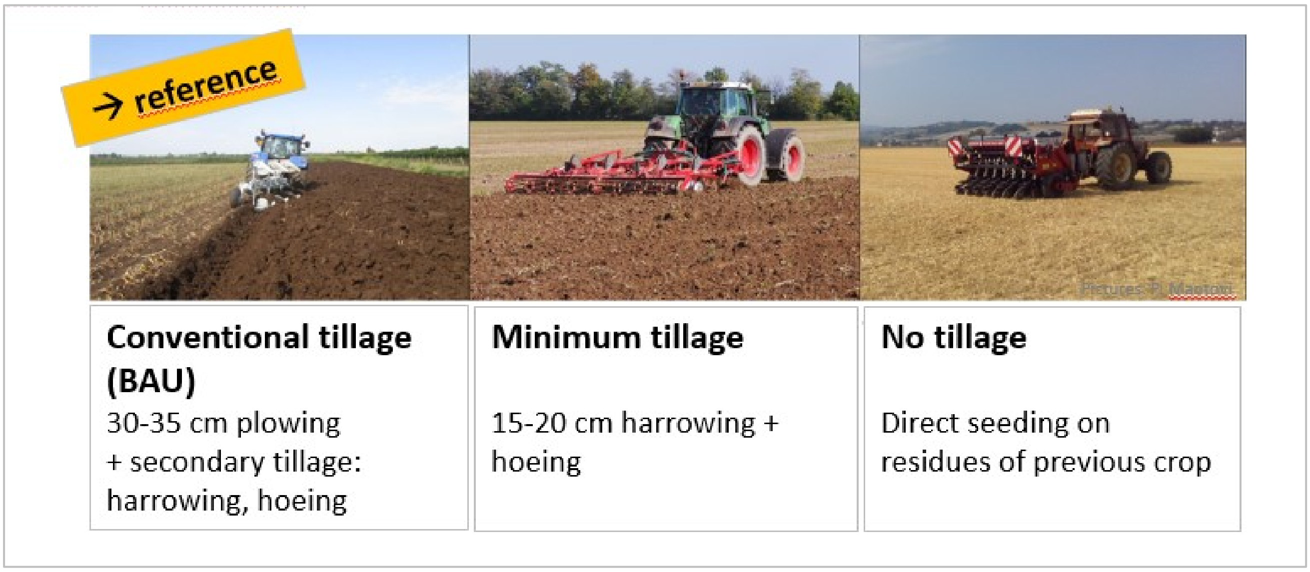


***Figure 9**: Considered scenarios and reference for the s System under study – Conservation tillage to increase water- and nutrient use efficiency and its effect on soil quality characteristics – conducted in IT.*

3.3.4. Fertilizer production from digestate by solar drying and testing of produced fertilizers in two different crop rotations (ES)

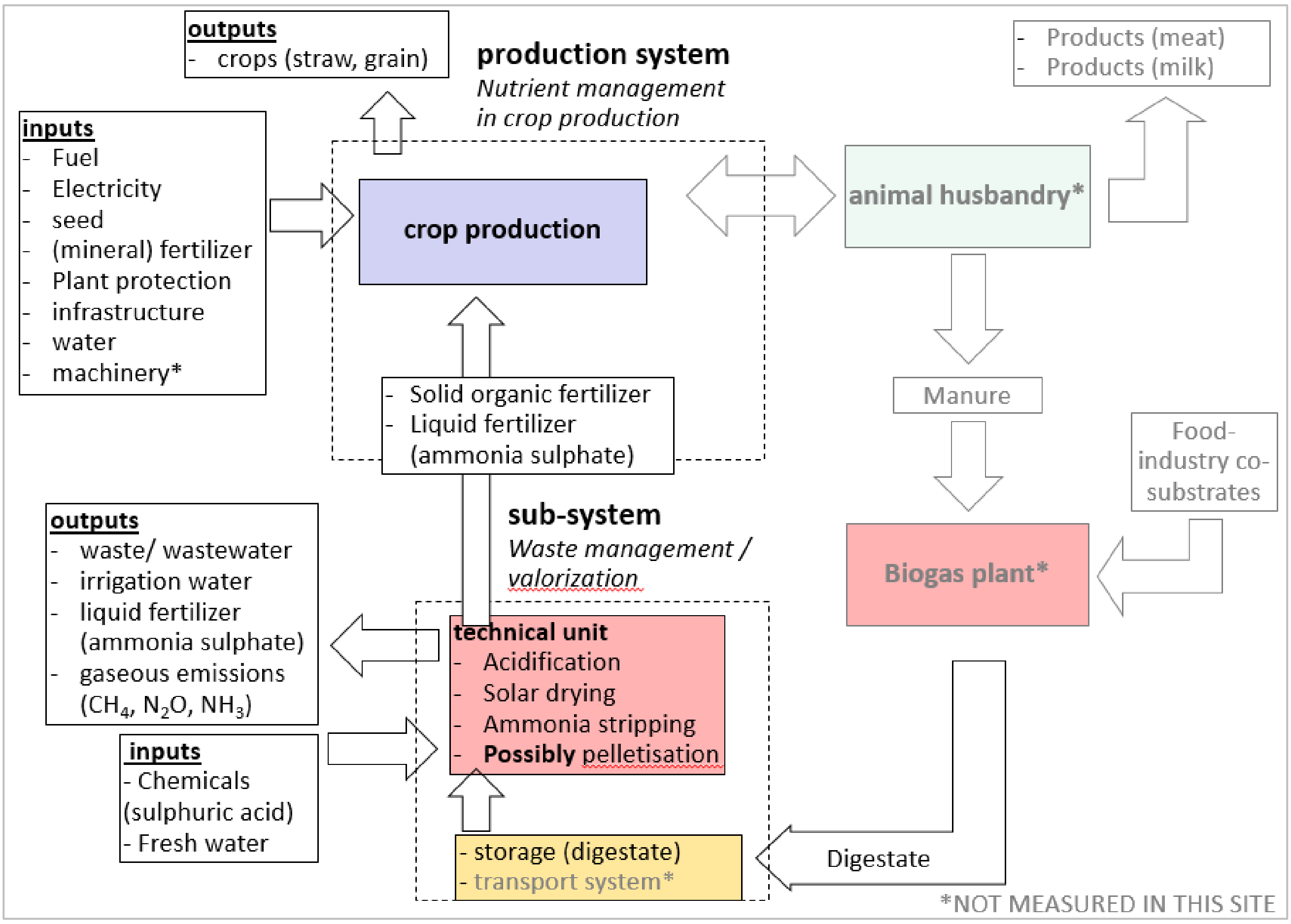


Figure 10: System under study – Fertilizer production from digestate by solar drying and testing of produced fertilizers in two different crop rotations – conducted in ES.

System and its function: WASTE MANAGEMENT and NUTRIENT MANAGEMENT IN CROP PRODUCTION

On-farm solar drying of digestate for better nutrient valorization and lower transport / storage / disposal costs (Figure 10). Solar dried digestates are tested as fertilizers in two field crop rotations: a cereal based crop rotation (wheat-barley-triticale) and a non-cereal based crop rotation (canola-pea-wheat) (Figure 11). The fertilizer efficacy of dried concentrated digestate is compared to fresh, untreated digestate. Nitrogen fertilization is applied per crop, but overall, the same amount of N is applied in each crop rotation. The FU is “1 Mg of crop yield”. Thus, the two crop rotations cannot directly be compared with each other, as the yield of the different crops is not comparable. This issue will be addressed using a system expansion procedure. Means of the crop rotations will be evaluated separately from each other for their environmental impacts.

System boundaries: Field level (crop production) and digestate treatment.

- Animal husbandry is not part of the system; the milk yield is not measured in the experiment.
- The biogas plant is not part of the system, as the biogas yield is co-dependent on other inputs.

Functional unit: 1 Mg of crop yield for mean of each crop rotation.

Allocation:

- Cereal based crop rotation: allocation based on monetary criteria. Straw of all cereal crops is used externally in animal husbandry.
- Non-cereal based crop rotation: no allocation for canola and pea; plant residues stay on the field and are incorporated. Allocation based on monetary criteria for wheat straw, which is used externally in animal husbandry.

Reference: application of raw digestate for each crop rotation.

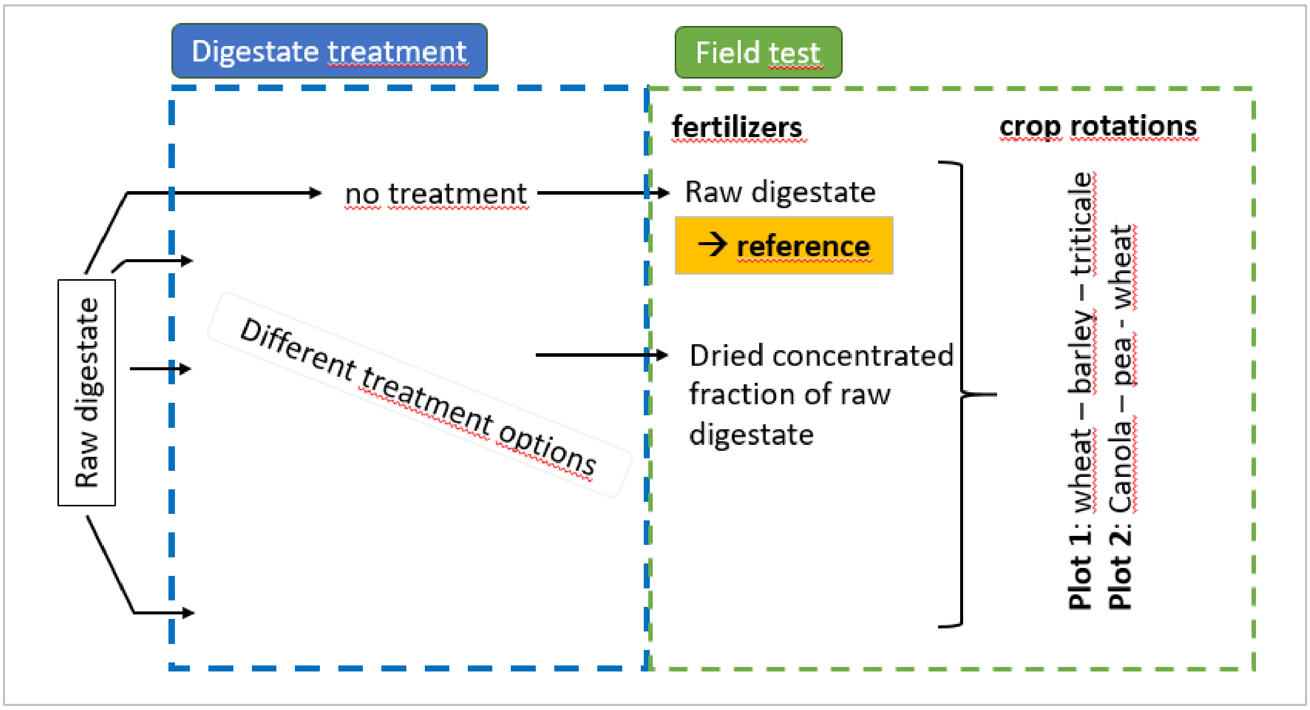


***Figure 11**: Considered scenarios and reference for the system under study – Fertilizer production from digestate by solar drying and testing of produced fertilizers in two different crop rotations – conducted in ES.*

3.3.5. Microfiltered digestate applied by fertigation to energy crops (maize and sorghum) to reduce mineral N fertilization (IT)

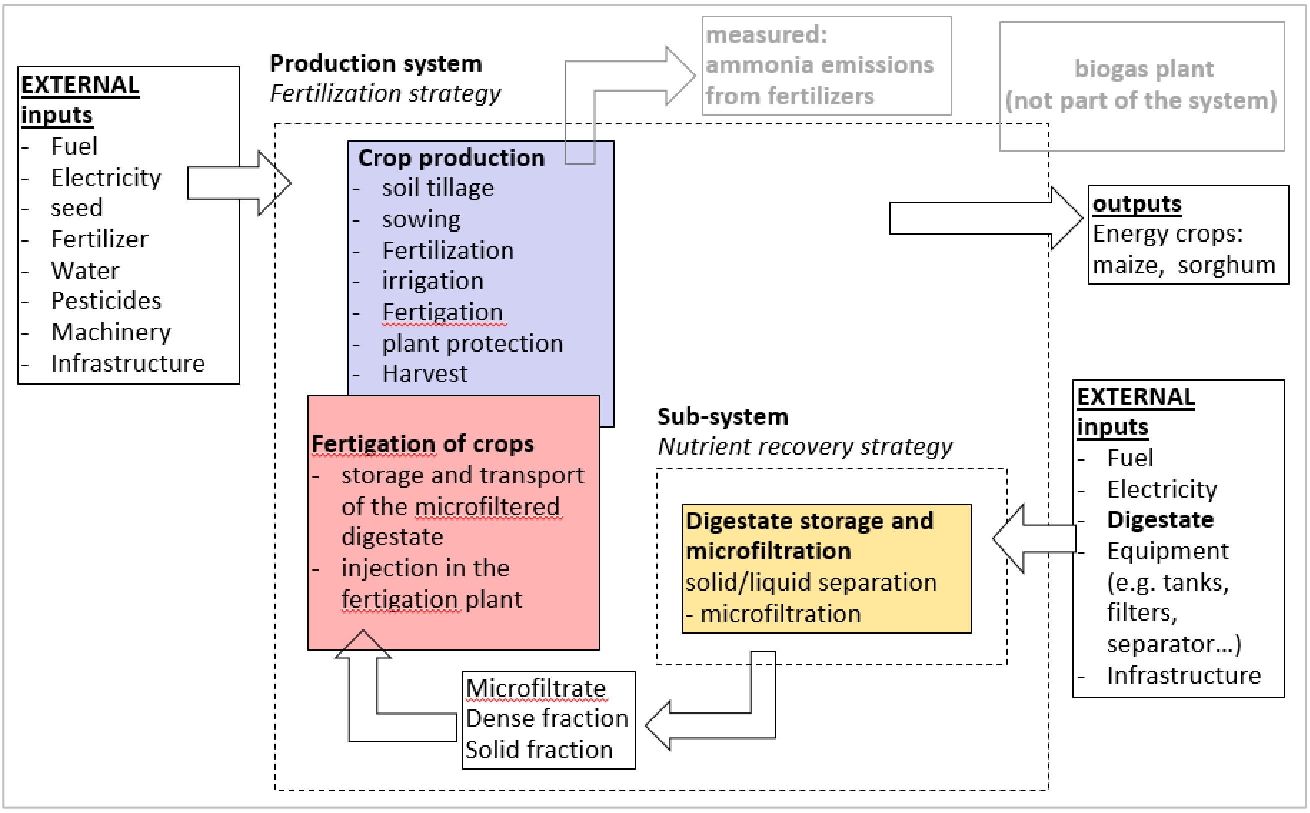


Figure 12: System under study – microfiltered digestate applied to energy crops by fertigation to reduce mineral N fertilization – conducted in IT.

System and its function: NUTRIENT RECOVERY STRATEGY and FERTILIZATION STRATEGY

Raw digestate is separated in solid and liquid fractions, the liquid fraction is microfiltered, the microfiltrate is used in fertigation of energy crops to tests its fertilizer efficacy (Figure 12). There are two levels of different fertilizers: raw digestate and microfiltered digestate. The application of raw digestate is followed by ploughing, and combined with mineral fertilization and sprinkler irrigation (= BAU treatment). The microfiltered fraction of digestate is applied by fertigation through drip line irrigation, and combined with the application of the solid/dense fraction of raw, separated digestate (Figure 13).

System boundaries: Field level. From harvest of soybean (2018) until harvest of maize (2019) and sorghum (2020), and microfiltrate production.

- No significant influence on crop yield and biogas yield is expected through the microfiltrate fertigation to plants, compared with BAU (at least in the first years of application), and the biogas yield also depends on other external inputs (e.g. cattle manure, wine production residues, etc). That is why it was decided in agreement with the CSL to leave the biogas plant out of the considered system.

Functional unit: 1 Mg of whole crop yield: maize (2019), sorghum (2020).

Allocation: no allocation. Whole plants are harvested for their use in energy production.

Reference: Application of raw digestate, followed by ploughing and combined with mineral fertilization and sprinkler irrigation (= BAU treatment).

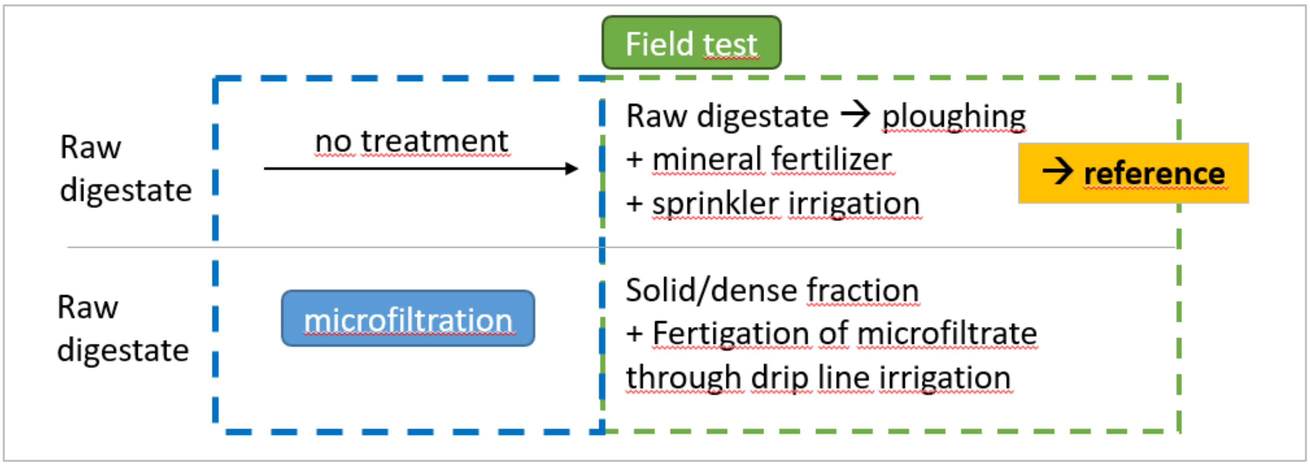


***Figure 13**: Considered scenarios and reference of the system under study – microfiltered digestate applied to energy crops by fertigation to reduce mineral N fertilization – conducted in IT.*

3.3.6. Production of novel N fertilizers from different substrates in the PONDUS plant and test of fertilizers and by-products in field experiments (DE + NL)

System and its function: NUTRIENT RECOVERY STRATEGY and FERTILIZATION STRATEGY

Different substrates are used in the PONDUS plant to produce mineral N fertilizers. These fertilizers and by-products are tested in field experiments with rye and maize (DE) and in grassland (NL), with the aim to reduce field N_2O-emissions.

The PONDUS plant is not yet running (January 2020). According to the current planning, two different substrates are to be used for fertilizer production in the PONDUS plant: the liquid fraction of agricultural digestate and the liquid fraction of digestate from municipal organic waste.

There are two possible business models for the PONDUS fertilizer plant:

1. On-farm production of mineral fertilizers on huge farms (3000 ha farmland) including biogas production.
2. Large-scale external production of mineral fertilizers, including there and back transport of manure/ digestate from surrounding farms and valorized products.
   - ➔ In discussions at the annual meeting, it was agreed on this second option, which includes storage and transport of inputs (slurry, digestate) and outputs (valorized products) (Figures 9, 10).

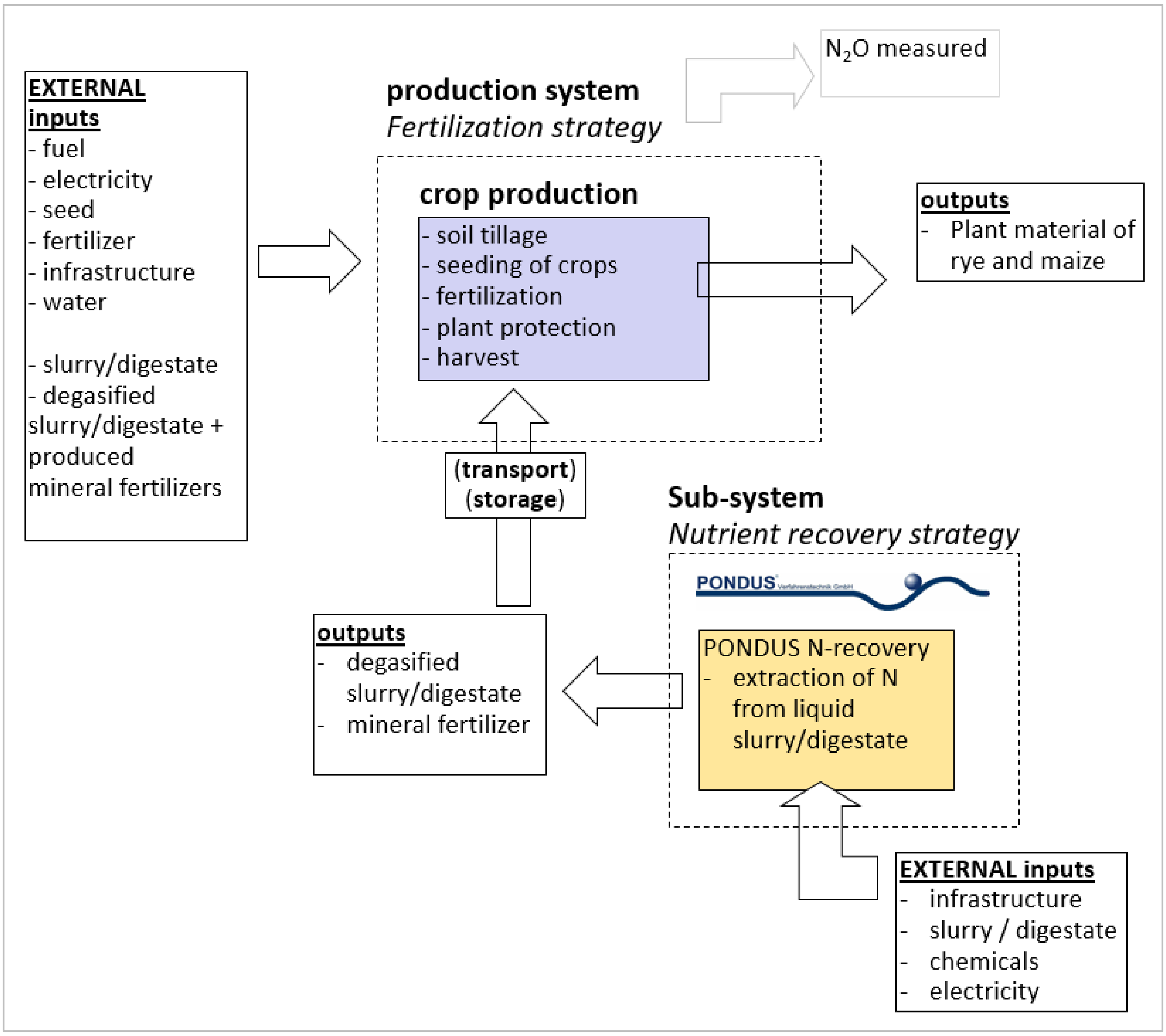


Figure 14: System under study – production of novel N fertilizers from different substrates in the PONDUS plant and test of different substrates in field experiments – conducted in DE.

In Germany (Figure 14), the produced fertilizers and by-products are tested in a field experiment with rye and maize. There will be a rye-maize crop rotation on the same field in one year (2020). There are five different levels of N fertilization: untreated substrate (= BAU), N-depleted substrate (PONDUS), N-depleted substrate + extracted N in mineral form (PONDUS), mineral N fertilizer, without N fertilization (Figure 15). All fertilized treatments receive the same amount of total N. The substrates produced in the PONDUS plants are considered as external inputs.

System boundaries: Field level, from harvest of pre-crop until harvest of rye/maize.

- The field experiment will start in April/May 2020. The exact location of the study site has not finally been decided (Jan. 2020), thus the pre-crop cannot be specified yet. This needs to be clarified with the CSL as soon as the experiment has started.

Functional unit: 1 Mg of whole rye / maize plants.

Allocation: No allocation. Whole plants are harvested and removed from the field.

Reference: Fertilization with untreated substrate (= BAU treatment).

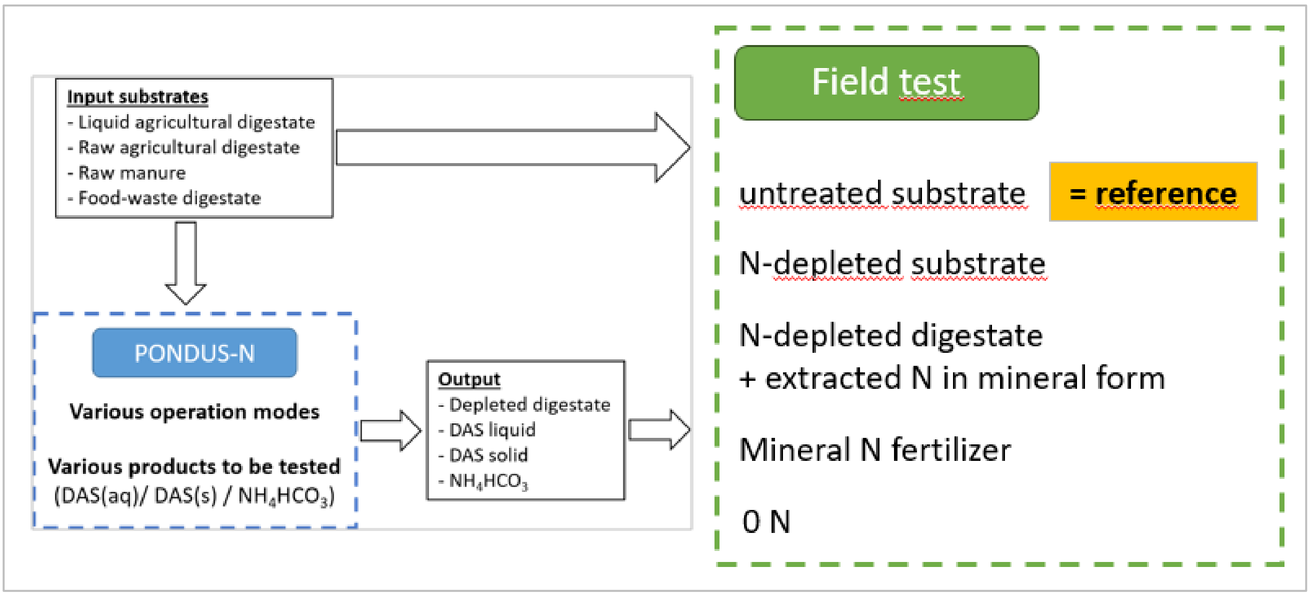


Figure 15: Considered scenarios and reference for the system under study – production of novel N fertilizers from different substrates in the PONDUS plant and test of different substrates in field experiments – conducted in DE.

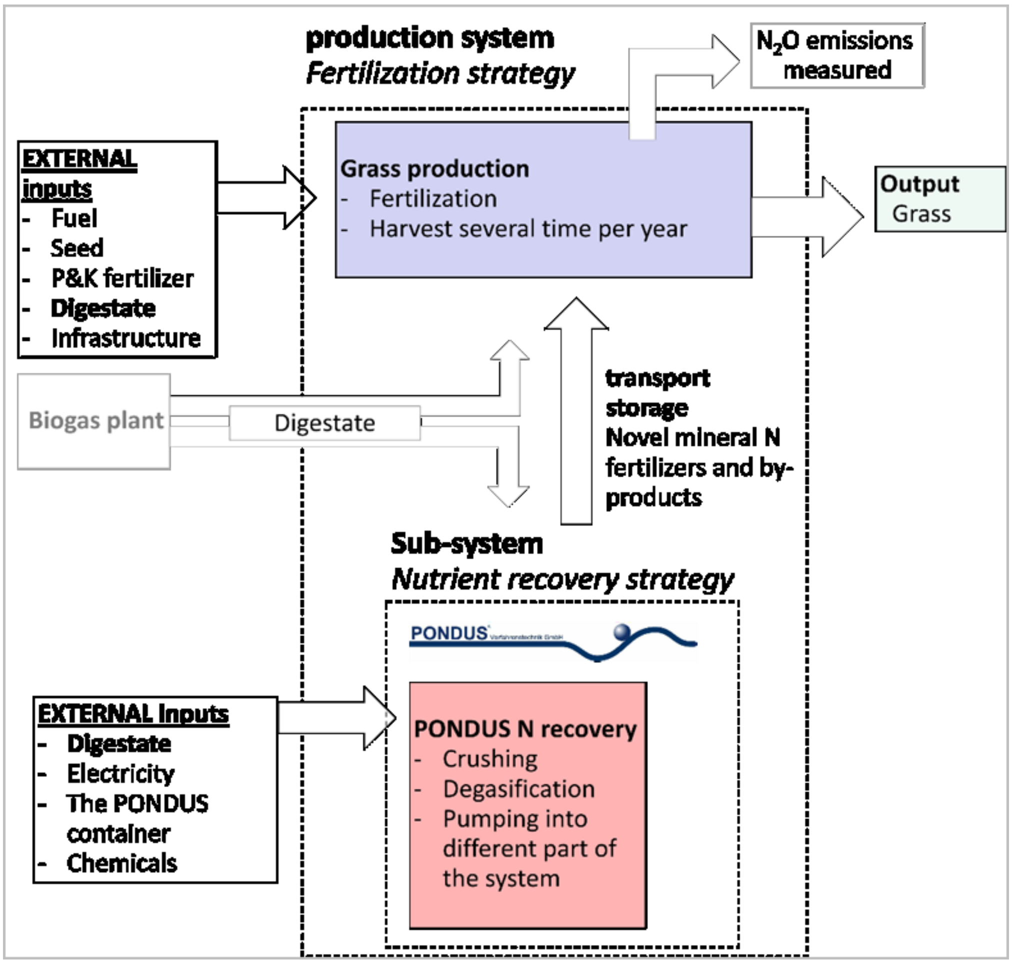


***Figure 16**: System under study – production of novel N fertilizers from different substrates in the PONDUS plant and test of different substrates in field experiments – conducted in NL.*

In The Netherlands (Figure 16), the produced PONDUS fertilizers and by-products are tested in a field experiment with different grassland species. There are three different levels of grass species: *Lolium perenne*, one *Trifolium* species and a mixture of the five species: *Lolium perenne*, *Festuca arundinacea*, *Phleum pratense*, *Trifolium pratense*, *Trifolium repens*. There are six different levels of N fertilization: untreated digestate (= BAU), N-depleted substrate (PONDUS), liquid Di-ammonium sulphate (PONDUS), Di-ammonium sulphate + N-depleted substrate (PONDUS), mineral N fertilizer, without N fertilization (Figure 17).

System boundaries: Field level, one season of grass.

Functional unit: 1 Mg of grass yield.

Allocation: no allocation. Grass is harvested and used as a whole.

Reference: Fertilization with untreated substrate.

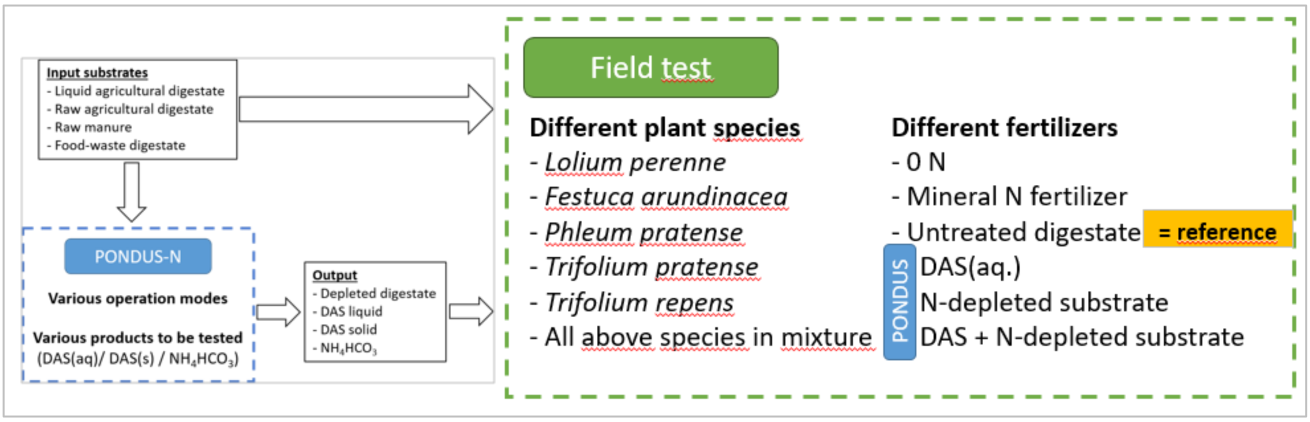


***Figure 17**: Considered scenarios and reference for the system under study – production of novel N fertilizers from different substrates in the PONDUS plant and test of different substrates in field experiments – conducted in NL.*

3.3.7. Test of novel P fertilizers from soybean waste water (NuReSys) in intensive grasslands (NL)

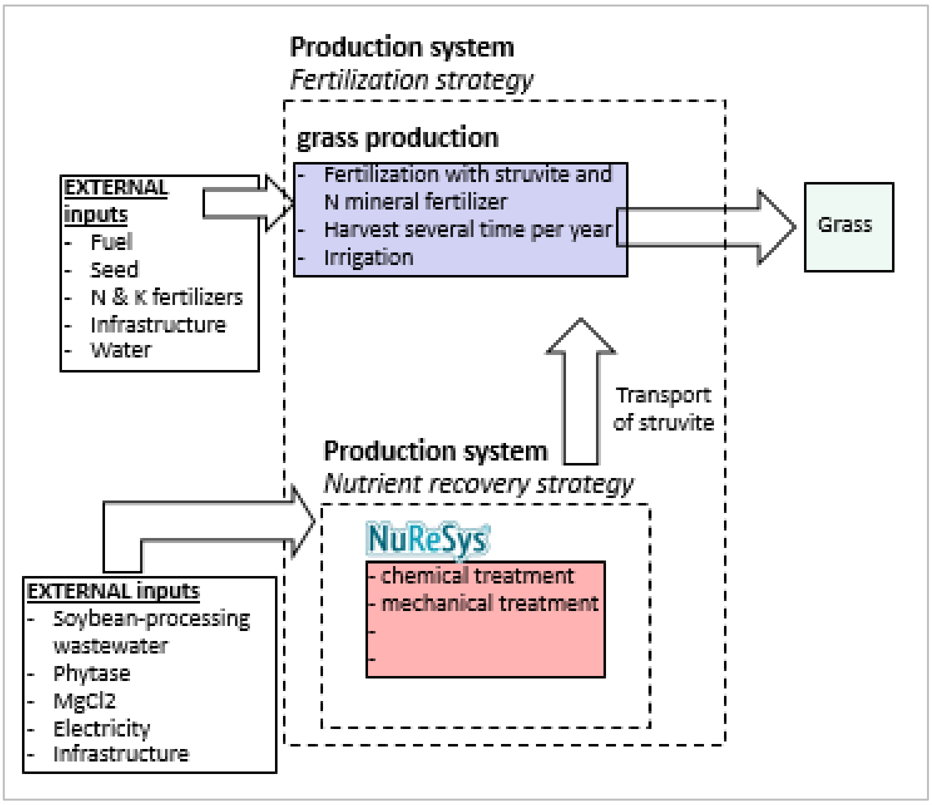


***Figure 18**: System under study – production of novel P fertilizers from Soybean wastewater in the NuReSys plant and field test of novel fertilizers in intensive grasslands – conducted in NL.*

System and its function: NUTRIENT RECOVERY STRATEGY and FERTILIZATION STRATEGY

Different P fertilizers are produced from soybean wastewater in the NuReSys plant (Figure 18). Fertilizers and by-products are tested in intensive grassland to replace phosphate rock - based fertilizers. There are five different levels of P fertilization: sludge compost (NuReSys), P-depleted sludge compost + NH_4-Struvite (NuReSys), P (K)-depleted sludge compost + K-Struvite (NuReSys), mineral P fertilizer (triple super phosphate), without P fertilization (Figure 19). The total amount of P is identical in all fertilized treatments.

Soybean wastewater is considered as waste stream without any monetary value. The NuReSys plant is not installed on the farm, but fertilizers are produced externally, which implies transport of fertilizers to the farm. According to the discussions at the annual meeting, realistic transport distance of fertilizers to the farm are assumed as follows:

- Up to 50-100 km for biosolids (P-compost)
- Up to 250 km for mineral fertilizers (struvites)

System boundaries: Field level. One season of *Lolium perenne*.

Functional unit: 1 Mg of *Lolium perenne*.

Allocation: no allocation. Grass is harvested and used as a whole.

Reference: Fertilization with conventional mineral P fertilizer (triple super phosphate).

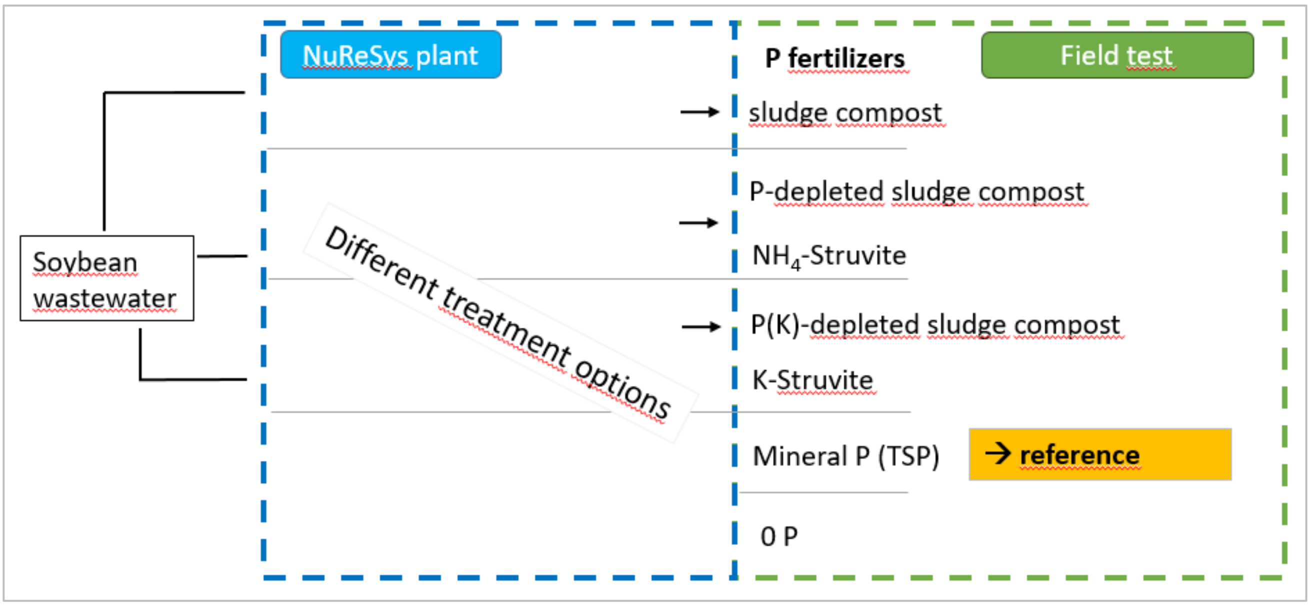


Figure 19*: Considered scenarios and reference for the system under study – production of novel P fertilizers from Soybean wastewater in the NuReSys plant and field test of novel fertilizers in intensive grasslands – conducted in NL.*

3.3.8. Soil application of acid whey to increase soil C storage (CZ)

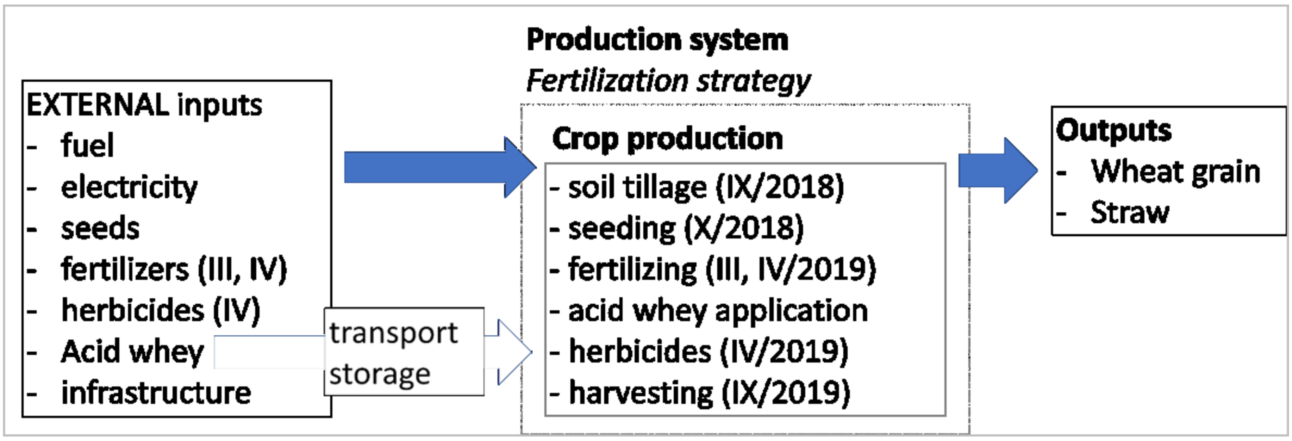


***Figure 20**: System under study – field application of acid whey to increase soil C storage under wheat production – conducted in CZ.*

System and its function: CARBON RECOVERY STRATEGY and FERTILIZATION STRATEGY

Separated acid whey is applied to a field experiment with winter wheat, to test its ability to increase soil C storage (Figure 20). There are five different levels of acid whey dosage on the field (L / plot): 65, 130, 260, 390 and 0 (without acid whey application) (Figure 21). These dosages are applied in the first year of the experiment (2019). In the second year of the experiment (2020/2021), applied acid whey dosages will be defined in dependency of its N content (kg N/ ha): 0, 120, 150, 180 and 210. Applied acid whey dosages of the third year of the experiment (2021/2022) will be defined based on the results of the previous seasons. The CSL will inform us about the applied dosages of the third year of the experiment as soon as they are defined.

A realistic business scenario was discussed at the annual meeting, concerning the proximity of a dairy plant as provider of acid whey (= external input). Assumed transport distance from dairy plant to field: 20 km. Cooled transport is not necessary for acid whey, as discussed at the annual meeting.

System boundaries: Field level, from harvest of pre-crop (maize grain, 2019) until harvest of wheat (2020).

Functional unit: 1 Mg of wheat grain.

Allocation: 50% of the straw remains on the field, 50% is used externally as animal bedding. No allocation for the straw that remains on the field, allocation based on monetary criteria for the part of the straw that is used externally.

Reference: wheat production without acid whey application.

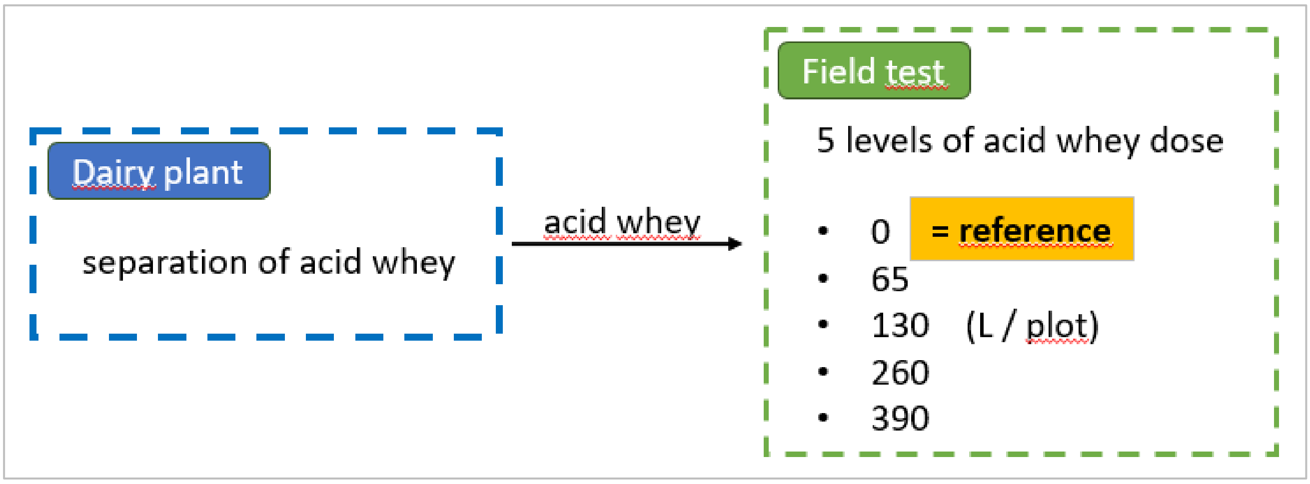


Figure 21*: Considered scenarios and reference for the first year of experiment of the system under study – field application of acid whey to increase soil C storage under wheat production – conducted in CZ.*

3.3.9. Precision feeding of cows and fertilization with manure from different feeding regimes (ES)

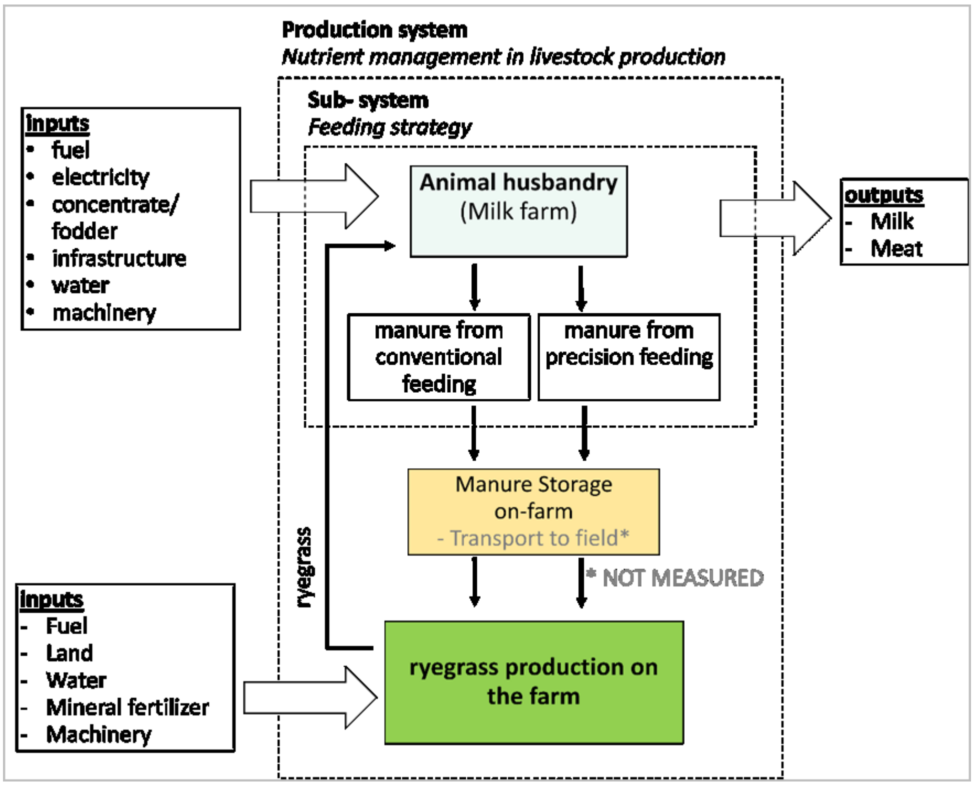


Figure 22: System under study – Precision feeding of cows and fertilization of forage crops with manure from different feeding regimes – conducted in ES.

System and its function: NUTRIENT MANAGEMENT IN LIVESTOCK PRODUCTION and FEEDING STRATEGY

The effect of precision feeding versus conventional feeding of cows on milk production is tested, with the aim to reduce mineral N fertilization. There are two different feeding regimes: conventional feeding (= ad libitum fodder range for cows, BAU treatment) and precision feeding (diet is individually adapted to the physiological condition of the single animal). The slurry from both different feeding strategies is collected separately and used to fertilizer forage crops, to test its N use efficiency (Figure 22). In addition, for each slurry there are two different application times tested: a single application at full rate before sowing (= BAU), and two applications (splitted application) (Figure 23). The nutrient (N) content of both slurries is expected to be different (reduced nutrient content in slurry from precision feeding). Thus, the same amount of N will be applied on each plot, but not the same total amount of slurry.

System boundaries: Farm gate.

Functional unit: 1 Kg ECM milk.

Allocation: Biophysical allocation. Main product = milk, co-product = meat.

Reference: Single application of slurry from conventional feeding at full rate before sowing (= BAU).

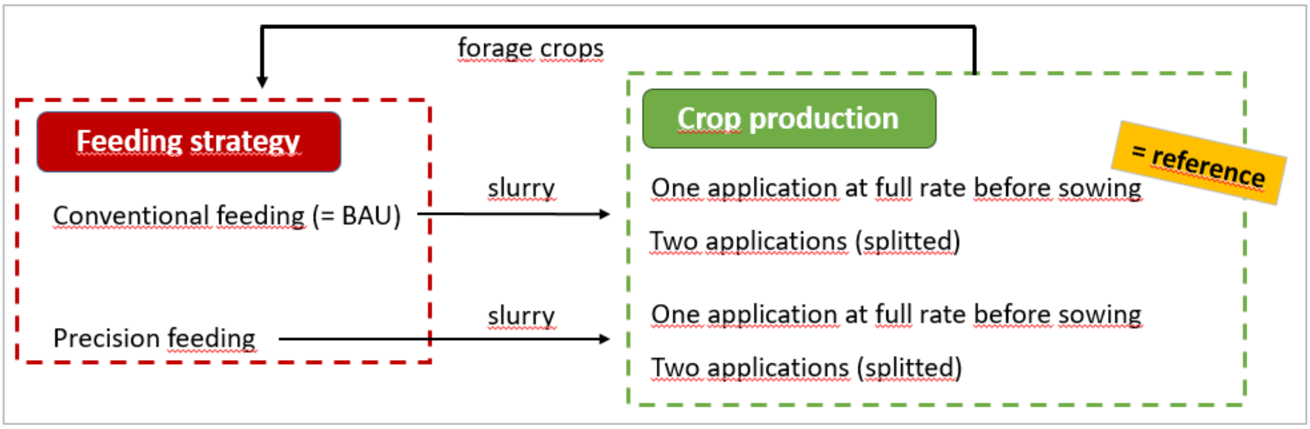


***Figure 23**: Considered scenarios and reference for the system under study – Precision feeding of cows and fertilization of forage crops with manure from different feeding regimes – conducted in ES.*

3.3.10. Extensive management of organic dairy farms in the Reine Lungau region (AT)

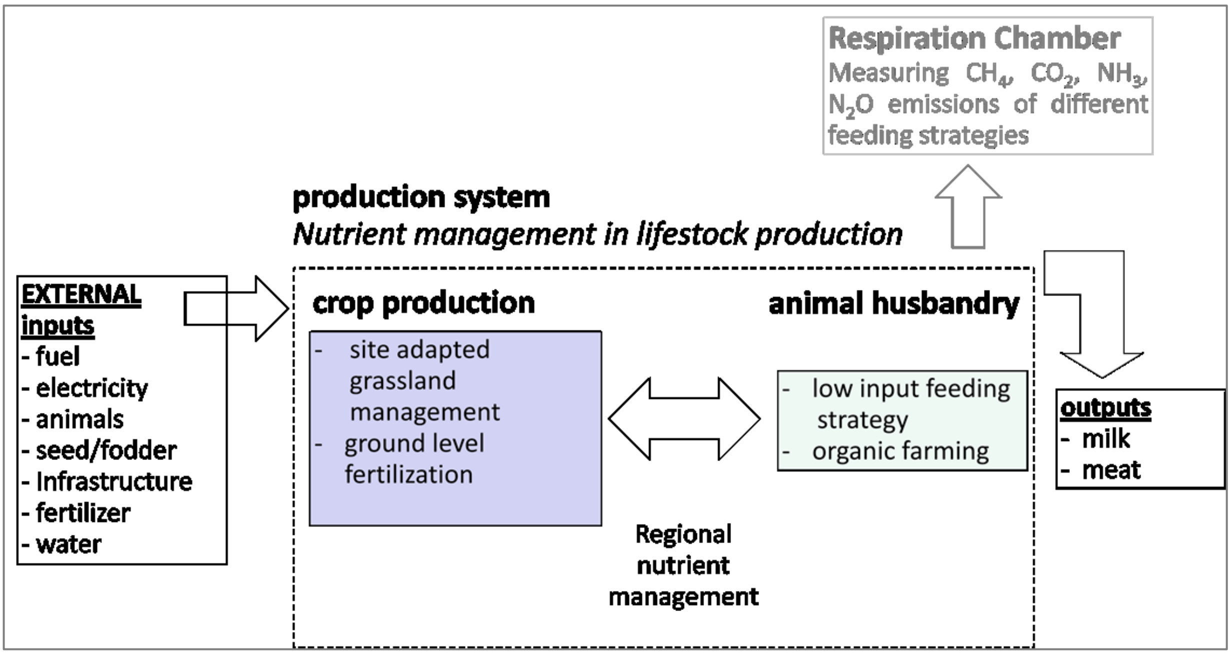


***Figure 24**: System under study – Extensive management and feeding of cows on organic farms in the study region Reine Lungau – conducted in AT.*

System and its function: NUTRIENT MANAGEMENT IN LIVESTOCK PRODUCTION

The organic dairy farms of the study region Reine Lungau are characterized by their extensive, regional fodder management (Figure 24), with a fodder ratio of > 90% forage and approximately 5% concentrates. Due to the different site conditions (cutting frequencies of grassland and different amount of arable land on each farm), there are huge differences in the average milk yield between the farms. These extensively managed farms of the study region Reine Lungau are compared to an average Austrian organically managed dairy farm with similar input-output ratio (Figure 25). The innovation to be assessed is the more extensive management in the Reine Lungau region, compared to a comparable average Austrian dairy farm.

System boundaries: Farm gate.

Functional unit: 1 Kg ECM milk.

Allocation: biophysical allocation. Main product = milk, co-product = meat.

Reference: Average Austrian organic dairy farm with similar input-output ratio like the farms of the study region Reine Lungau. The generic reference farm will be generated from national databases.

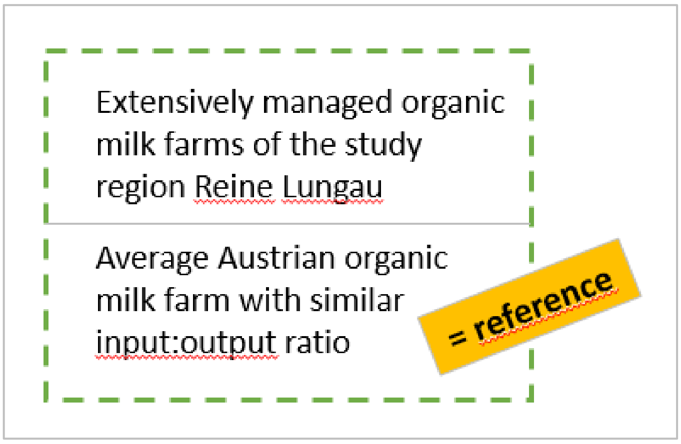


Figure 25: Considered scenarios and reference of the system under study – Extensive management and feeding of cows on organic farms in the study region Reine Lungau – conducted in AT.

4. FURTHER STEPS

4.1. Data collection

Foreground data for the calculations will be collected from the experiments conducted within the CS. The data collection from CS on crop level and farm level will be conducted by AREC through the online tool "CA capture". A Skype meeting with the CS leaders was held in January 2020, where the required data was discussed in a Case Study specific manner. Personal on-site visits will be conducted by AREC to assist CS leaders with data entry at each CS site between April – Sept 2020. By this, AREC ensures the completeness and high quality of the data. In some cases, emission factors might have to be estimated according to the knowledge of the CSL. KWB will collect technical data for the assessed technological innovations through a data demand sheet. Background data will be collected by AGRO, AREC and KWB from existing databases (see chapter 2.2).

4.2. Calculation

The environmental assessment will be performed as iterative loops between AGRO, AREC, KWB and the case study partners and is scheduled between the months 19-39, as described above (chapters 2.1.1-2.1.3).

REFERENCES

Boulay A.M., Bare J., Benini L., Berger M., Lathuillière M.J., Manzardo A., Margni M., Motoshita M., Núñez M., Pastor A.V., Ridoutt B., Oki T., Worbe S. & Pfister S., 2017. The WULCA consensus characterization model for water scarcity footprints: assessing impacts of water consumption based on available water remaining (AWARE). International Journal of Life Cycle Assessment 1-11.

EC-JRC-IES, 2011. Recommendations for life cycle impact assessment in the European context - based on existing environmental impact assessment models and factors. Luxemburg, 159 p., Available at http://eplca.jrc.ec.europa.eu/uploads/ILCD-Recommendation-of-methods-for-LCIA-def.pdf.

Frischknecht R., Althaus H.J., Bauer C., Doka G., Heck T., Jungbluth N., Kellenberger D. & Nemecek T., 2007. The environmental relevance of capital goods in life cycle assessments of products and services. International Journal of Life Cycle Assessment, 12: 7-17.

Gaillard G. and Nemecek T., 2009. Swiss Agricultural Life Cycle Assessment (SALCA): An integrated environmental assessment concept for agriculture. In: International Conference "Integrated Assessment of Agriculture and Sustainable Development, Setting the Agenda for Science and Policy", Egmond aan Zee, Niederlande. AgSAP Office, Wageningen University, 134-135.

Guinée J.B., Gorrée M., Heijungs R., Huppes G., Kleijn R., de Koning A., van Oers L., Wegener Sleeswijk A., Suh S., Udo de Haes H.A., de Bruijn H., van Duin R., Huijbregts M.A.J., Lindeijer E., Roorda A.A.H. & Weidema B.P., 2001. Life cycle assessment - An operational guide to the ISO standards. Ministry of Housing, Spatial Planning and Environment (VROM) and Centre of Environmental Science (CML), Den Haag and Leiden, Netherlands.

Hauschild M.Z. & Potting J., 2005. Spatial differentiation in life cycle impact assessment - The EDIP2003 methodology. The Danish Ministry of the Environment, Environmental Protection Agency, Copenhagen, Environmental News, 195 p., Available at http://www2.mst.dk/udgiv/publications/2005/87-7614-579-4/pdf/87-7614-580-8.pdf.

Herndl M., Baumgartner D.U., Guggenberger T., Bystricky M., Gaillard G., Marton S., Lansche J., Fasching C., Steinwidder A., Nemecek T., 2015. Einzelbetriebliche Ökobilanzierung landwirtschaftlicher Betriebe in Österreich. Abschlussbericht FarmLife. Available at https://www.raumberg-gumpenstein.at/cm4/de/component/jdownloads/viewdownload/1791-2386-farmlife/29085-einzelbetriebliche-oekobilanzierung-landwirtschaftlicher-betriebe-in-oesterreich.html.

Hersener J.-L., Baumgartner D.U., Dux D., Aeschbacher U., Alig M., Blaser S., Gaillard G., Glodé M., Jan P., Jenni M., Mieleitner J., Müller G., Nemecek T., Rötheli E., Schmid D., 2011. Zentrale Auswertung von Ökobilanzen landwirtschaftlicher Betriebe (ZA-ÖB). Schlussbericht. Forschungsanstalt Agroscope Reckenholz-Tänikon ART, Zürich/Ettenhausen.

IPCC, Stocker, T.F. et al. (eds). Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York. 1535.

ISO, 2006. ISO 14044 - Environmental management - Life cycle assessment - Requirements and guidelines. International Standardization Organization, Genf.

Koch P., Salou T., 2013. AGRIBALYSE®: Rapport méthodologique - Version 1.0. ADEME, Angers. Internet: http://www.ademe.fr/agribalyse; zuletzt abgerufen: 20.11.2013.

Laurent A., Olsen S.I. & Hauschild M.Z., 2011. Normalization in EDIP97 and EDIP2003: Updated European inventory for 2004 and guidance towards a consistent use in practice. International Journal of Life Cycle Assessment, 16: 401-409.

Nemecek, T., Freiermuth Knuchel, R., Alig, M., Gaillard, G., 2010. The advantages of generic LCA tools for agriculture: examples SALCAcrop and SALCAfarm. In: Notarnicola, B., Settanni, E., Tassielli, G., Giungato, P. (Hrsg): Proceedings of the 7th International Conference on Life Cycle Assessment in the Agri-Food Sector. Università degli Studi di Bari Aldo Moro, Bari, Italien. S. 433-438.

Posch M., Seppälä J., Hettelingh J.P., Johansson M., Margni M. & Jolliet O., 2008. The role of atmospheric dispersion models and ecosystem sensitivity in the determination of characterisation factors for acidifying and eutrophying emissions in LCIA. International Journal of Life Cycle Assessment, 13: 477-486.

Rosenbaum R.K., Bachmann T.M., Gold L.S., Huijbregts M.A.J., Jolliet O., Juraske R., Koehler A., Larsen H.F., MacLeod M., Margni M., McKone T.E., Payet J., Schuhmacher M., van de Meent D. & Hauschild M.Z., 2008. USEtox-the UNEP-SETAC toxicity model: recommended characterisation factors for human toxicity and freshwater ecotoxicity in life cycle impact assessment. International Journal of Life Cycle Assessment, 13: 532-546.

Seppälä J., Posch M., Johansson M. & Hettelingh J.P., 2006. Country-dependent characterisation factors for acidification and terrestrial eutrophication based on accumulated exceedance as an impact category indicator. International Journal of Life Cycle Assessment, 11: 403-416.