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Nutri2Cycle

D.1.2 Protocol for the mapping, analysis and benchmarking of CNP flows and their stoichiometry in farming systems

Deliverable: Protocol for the mapping, analysis and benchmarking of CNP flows and their stoichiometry in farming systems

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Nurturing the Circular Economy

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1. Introduction

1.1 Project description

Nutri2Cycle is a H2020 EU project and aims to enable the transition from the current (suboptimal) nutrient management in European agriculture to the next-generation of agronomic practices, characterized by an improved upcycling of nutrients and organic carbon. This will help to decrease greenhouse gas (GHG) emissions, reduce soil degradation, improve water quality, and reduce the EU dependence on imported nutrients (especially phosphorus).

The project is structured in different work packages (Figure 1.1). This protocol (Deliverable 1.2) is part of WP1, which deals with 'Baseline determination and toolbox development'. In this WP the baseline on current nutrient flows and environmental performance will be set, against which the impact of the innovations will be evaluated. In WP2 a total of about 24 innovations will be selected from a longlist of 60 innovations, aimed at reducing GHG and nutrient losses via innovative management systems and technologies to better close C, N and P cycles in the investigated farm systems. In WP3 the environmental and economic impact of these innovations will be assessed at farm scale, whereas WP4 will assess the macro-economic and environmental impact at regional and European scales.

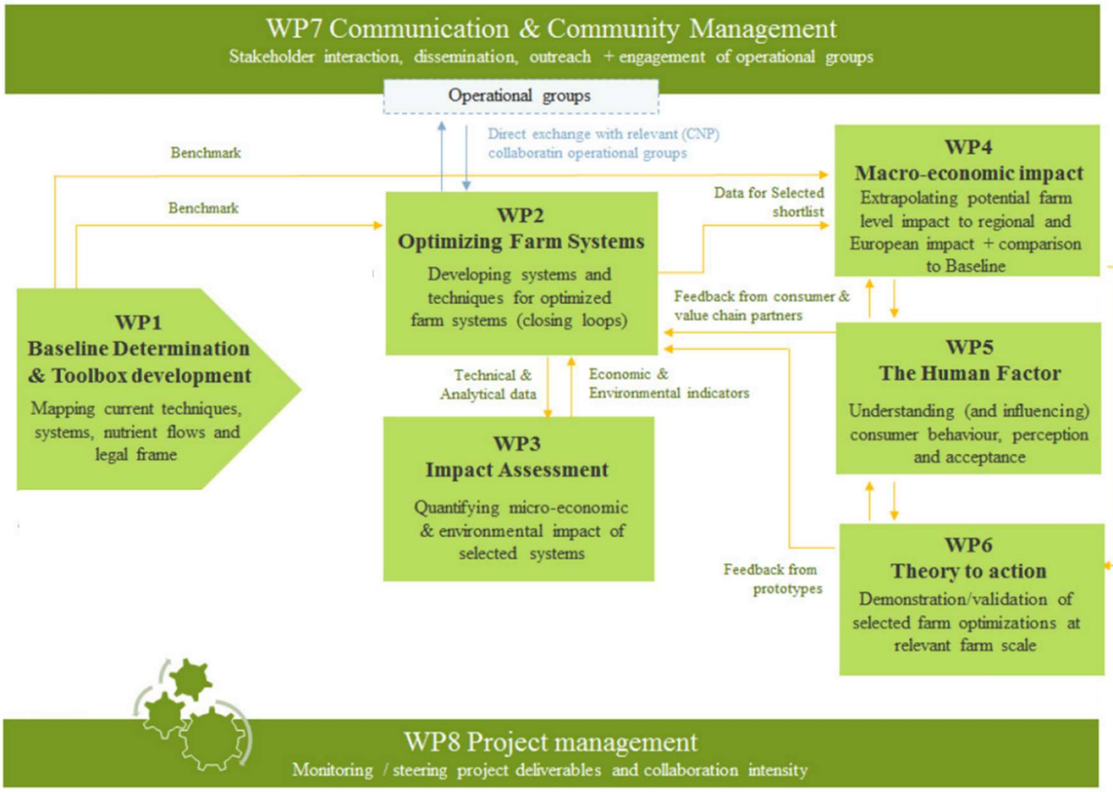

Figure 1.1. Pert chart of the Nutri2Cycle project

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This report is the deliverable of Task 1.1 (Development of protocols for analysis and assessment of CNP flows in farming systems), which is led by Wageningen Research (WR), with contributions from UCPH, Ugent, PCz, Thuenen, ISA and IRTA.

1.2 Objectives

The objective of this protocol is to provide common and uniform guidance for a comprehensive and integrated analysis and assessment of CNP stocks, input and output flows, and losses to the environment, in main farming systems in Europe.

The guidance refers to i) general guidance in terms of common use of definitions, system boundaries and indicators (the indicators are described in detail in Deliverable 1.1), ii) guidance for data collection of CNP flows (including losses) on farms and iii) guidance for modelling of CNP flows and stocks in Nutri2Cycle assessments of baselines and innovations for closing CNP cycles.

1.3 Structure of the protocol

The objectives of the current protocol are examined in three sections. Section 2 is the general protocol for Nutri2Cycle assessments, which includes the system boundaries for the analyses in the project, a description on how analyses at different scales are used within the project, sets the definitions of relevant terminology, and provides definitions of the selected set of farm/agro-typologies, the indicators to be used throughout the project and the selection procedure for shortlisting of solutions.

Section 3 is a protocol specifically aimed at the modelling work that is proposed in Nutri2Cycle. This section will give a short description of the models that are involved and their proposed use in the different work packages and the linkage of the model results.

Section 4 is the protocol for the primary data collection to assess CNP flows and stocks at farm level for the baseline determination in WP1 and subsequent analysis of the impact of innovations in WP3. This includes the variables to be collected, guidance for the selection of the farms and a discussion on data acquisition, storage and accessibility.

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2. General protocol Nutri2Cycle

2.1 System boundaries

The call text of this H2020 project explicitly mentions the farm and regional scales in the title 'SFS-30-2017: Closing loops at farm and regional levels to mitigate GHG emissions and environmental contamination - focus on carbon, nitrogen and phosphorus cycling in agro-ecosystems'. The call text lists the following expected impacts to be addressed:

- effective solutions for C-, N- and P-efficient agro ecosystems;
- improved overall sustainability and innovation capacity of the farming systems;
- reduction of environmental impact: reduced GHG emissions, protected and enhanced soil carbon stocks, improved ground- and surface-water quality;
- integrated scientific support for relevant EU policies (e.g. Common Agricultural Policy, Water Framework Directive, sustainable use of pesticides, climate change objectives); and
- strengthened transdisciplinary research for long-lasting implementation of results.

For the assessment of the impacts of the innovative systems and techniques that will be developed and tested in Nutri2Cycle, a clear system boundary is required. Over the last years, several studies have been published that assess nutrient flows at different scales. For a full picture of the nutrient flows from food production in the society, a whole food chain approach is required, which can show where in the system the largest losses occur. Examples of such studies are for N and P in China (Ma et al., 2010), detailed P flows for EU member states (van Dijk et al., 2016) and high-resolution nutrient flow analysis for Flanders (Coppens et al., 2016).

As the focus of Nutri2Cycle is on reducing CNP losses to the environment by improving the efficiency of the CNP flows within the agricultural system, a society wide system boundary would be too broad for the intended purposes. Figure 2.1 shows a schematic illustration of the food system and the nutrient flows between the different compartments. The red box shows the system boundary that will be used within Nutri2Cycle for the baseline determination and the impact assessment of the proposed innovations. This includes the primary agricultural sector of crop and livestock production, but also the processing of manure and residues and the incoming and outgoing CNP flows to and from these compartments. These three compartments are also the main pillars of the Nutri2Cycle project. This means that food (and non-food) processing and the consumption compartment are outside the system boundary, but flows of CNP from agricultural residues, organic (food) waste and sludge towards new use in the agricultural sector are within the system boundary. However, in WP5 "the human factor" the project will also look at the consumption side. The effects of possible shifts in consumption will be assessed with the CAPRI model, but this is not directly linked to the other work and assessments in WP1, WP3 and WP4.

The innovative systems and techniques that will be developed and assessed in the project are aimed at i) reducing nutrient and GHG losses from the crop and livestock production (comprising innovative solutions for optimized nutrient use and reduced GHG emissions in animal husbandry, innovative soil, fertilisation and crop management systems and practices and tools, techniques and systems for higher-precision fertilization), ii) bio-based fertilisers (N, P) and soil enhancers (OC) from agro-residues and iii) novel animal feeds produced from agro-residues. This should ultimately decrease the import of feed and mineral fertilizer and reduce the losses to the environment as indicated in Figure 2.1.

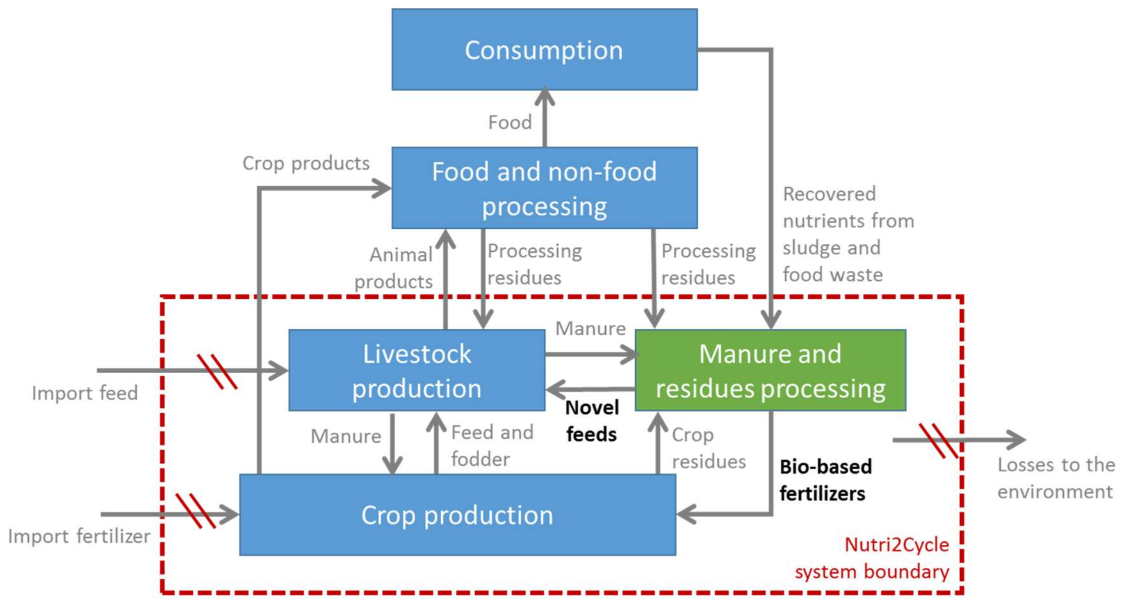

Figure 2.1. Schematic representation of the main nutrient flows in the food system (based on van Dijk et al., 2016) and the system boundary to be used in the assessments in Nutri2Cycle (dashed red box)

2.2 Scales in Nutri2Cycle

Spatial scale

For the assessment of innovative systems and techniques for closing nutrient cycles and reducing CNP losses, it is important to define the scale at which the impact is assessed. Closing nutrient loops at farm scale may require other measures and tools than closing loops at regional scale and assessing nutrient losses at field scale requires other models compared to regional scale impact assessment. In the project description different scale levels are mentioned, including farm, agro-ecology systems, landscape, sector and EU. In this protocol we aim for clear use of scales in the assessments within Nutri2Cycle.

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The main scales that will be distinguished in the project are illustrated in Figure 2.2.

- **Field**: Innovations working primarily at the field scale such as new fertilizer products, precision agriculture etc. will be tested and assessed at field scale. The field scale process-based models SWAP-ANIMO and DAISY will be used to assess the impacts of these innovations on emissions to water and air and effects on soil quality.
- **Animal**: Within Nutri2Cycle little or no specific work is foreseen at the animal scale, although some of the innovations might be related to novel feed types which might have impacts on animal performance and animal-related emissions. The use of detailed models at animal scale is not foreseen. However, effects at animal production unit scale may become evident at farm scale, and experimental data from WP2 related to the animal scale will be used in the farm scale model, which will address CNP flows in feed intake and excretion.
- **Digester / processing**: For innovations related to the processing and improved management of residues (crop, feed) and manure, the technical unit will be the relevant scale. For more small scale processing, this can be a unit on a farm based on local residues or manure, but larger scale processing units based on regional residue streams are often not located on farms. No detailed models for simulating the processes will be used, but the farm and regional models will address them in a aggregated way.
- **Farm**: At the farm scale the results from the field, small scale processing and animal scale will be integrated. For the environmental modelling at farm level the model MITERRA-Farm will be developed and used in WP1 and WP3, based on the calculation rules and databases of the MITERRA-Europe model. Using this model at the farm scale makes the integration to the regional scale easier.
- **Regional and member state**: For regional scale the environmental model MITERRA-Europe and the agricultural sector model CAPRI are used in WP4. These models will make use of the data and results of the WP1, 2 and 3, and upscale the application of the innovations for certain scenarios to regional and member state level. The models can make use of derived emission factors from the modelling with the detailed process-based models in WP1 and WP3.

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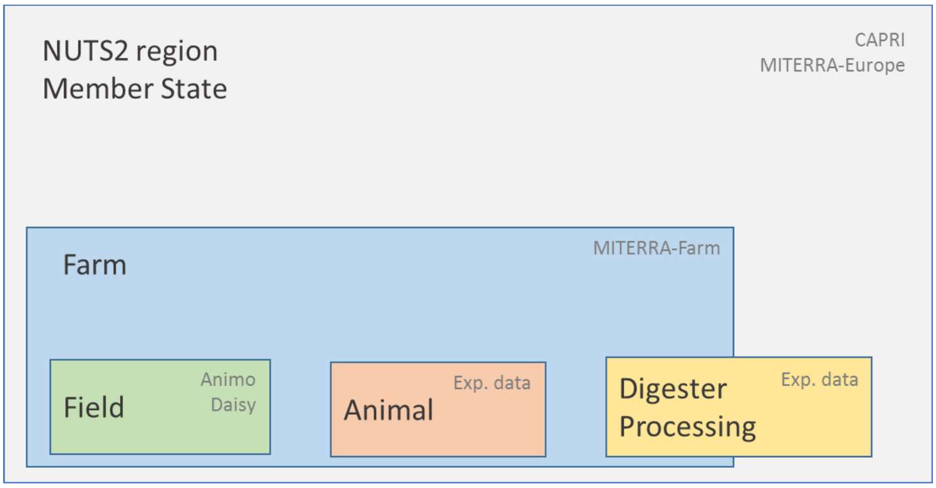

Figure 2.2. Illustration of the different spatial scales that are used in Nutri2Cycle. For each scale level is also indicated which models will be used.

Temporal scale

Besides the spatial scales that are distinguished in the project, also agreement on the temporal scale of the analyses of the different innovations is required. Some of the technical innovations might be monitored at daily or even shorter time scales, and also detailed process based models often run at a daily time scale. On the other side some processes act slowly and can only be monitored at longer times scales, like the built up of organic carbon in soils, which typically takes decades or even centuries to reach a new equilibrium.

We propose to present all results from the Nutri2Cycle project at an annual time scale. The underlying monitoring or modelling data can be at shorter time scales, but these results will all be translated into annual outcomes. This annual period can be a calendar year, but might also be linked to a crop cycle or data collection period (e.g. harvest to harvest), as long as this is clearly indicated. Presenting outcomes at annual basis will make the impacts comparable and this is also in line with LCA calculations, which are often based on annual input data.

For some impacts, like the effect on soil organic carbon and soil quality, but also some economic parameters, like return on investment, a longer time scale should be considered. This can be a 10-20 year period, which is a relevant time period to oversee for a farmer linked to an investment cycle. However, for some assessments, especially the contribution of soil carbon sequestration to mitigate global warming, a longer time span of 100 year is often included in modelling of impacts on soil C sequestration, linked to the global warming potential values of GHGs, for which a 100-year time span is commonly used. Nevertheless, these longer time scale results also have to be recalculated to an annual cost or environmental impact to be comparable with other impacts.

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2.3 Definitions

The call text and proposal include several terms for which often no common and universally agreed definitions and/or interpretations exist. For the purpose of the Nutri2Cycle project, a selection of terms has been defined below.

Animal nutrient balance: Nutrient input-output balance at animal level or at herd level, expressed in kg per animal per yr. Nutrients in feed intake are the inputs, while the nutrients in animal products (egg, milk, meat) are considered the outputs. The difference between input and output is equivalent to the amounts of nutrients in manure (at the herd level, provided there are no stock changes). This holds for nutrients, but not for carbon, as considerable respiration losses take place in the animal and emissions of CO_2 and CH_4.

Baseline: Reference situation, defined for a particular region (and farming system) and year, in terms of activity data (agricultural characteristics) and performances (inputs, outputs, efficiency, emissions).

Bio-based fertilisers: Organic fertilisers produced from organic residues following some treatment. This would suggest that animal manure is a bio-based fertiliser only following a treatment of the raw manure. Furthermore, bio-based fertilisers may also comprise inorganic materials, e.g. after thermal treatment of organic waste leading to a carbon free ash product. Please note that there are low and high-quality bio-based fertilisers, and that the composition of bio-based fertilisers is far from uniform.

Closing loops: Recycling and utilization of by-products and wastes from different trophic levels within the food system, and minimising unwanted losses of CNP to air, groundwater and surface waters, while considering accumulations of CNP inside the system (e.g. soil). Losses of CNP can be expressed in terms of kg per ha per year and in terms of kg per kg produce. Closing loops has also a meaning in bringing biomass production and consumption sites closer to each other, at regional scales, and in a better utilization (cascading) of biomass. In Nutri2Cycle project, emphasis is on the first definition, so on recycling and utilization of by-products and wastes and minimising losses to the wider environment.

Farm nutrient balance: Nutrient input-output balance at farm level, expressed in kg per ha per yr. Also called a partial farm nutrient balance, as the nutrient losses are not accounted for (the balance or surplus of nutrients (inputs – output in products) will either accumulate in the system or are lost to the wider environment). All nutrient inputs and outputs that pass the farm-gate will have to be recorded. In addition, inputs via atmospheric deposition and biological N_2 fixation have to be considered. See the guidance document of the EU Nitrogen Expert Panel (Oenema et al., 2015).

Fertiliser replacement value (FRV): The effectiveness of nutrients from bio-based fertilisers and residues relative to the effectiveness of nutrients from common synthetic fertilisers used in agriculture. The effectiveness can be expressed in terms of yield increase and in terms of nutrient uptake increase relative to a control treatment.

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Life-cycle assessment: a cradle-to-grave analysis to assess environmental impacts of a technique, process and/or system, associated with all the stages of a product's life from raw material extraction through processing, distribution, use, maintenance, and disposal or recycling. Different types of life-cycle assessment are being considered.

Livestock units: The recalculation of animal number to a standard unit, called livestock unit. Here, we follow the definitions of Eurostat. The reference unit used for the calculation of livestock units (=1 LSU) is the grazing equivalent of one adult dairy cow producing 3 000 kg of milk annually, without additional concentrated foodstuffs. Source: Eurostat, Annex I of Commission Regulation (EC) No 1200/2009)[1].

Animal species	Animal categories	LSU
Bovine animals	Under 1 year old	0.400
	1 but less than 2 years old	0.700
	Male, 2 years old and over	1.000
	Heifers, 2 years old and over	0.800
	Dairy cows	***1.000***
	Other cows, 2 years old and over	0.800
Sheep and goats	Sheep and goats	0.100
Equidae	Equidae	0.800
Pigs	Piglets having a live weight of under 20 kg	0.027
	Breeding sows weighing 50 kg and over	0.500
	Other pigs	0.300
Poultry	Broilers	0.007
	Laying hens	0.014
	Ostriches	0.350
	Other poultry	0.030
Rabbits	Rabbits, breeding females	0.020

Nutrient cycling: The continued movement and use (with possible temporary accumulations) of nutrients between different compartments (soil, plants, animals, humans, water, air) and trophic levels in the biosphere.

Nutrient stoichiometry: the ratio of nutrients, in wt/wt or mol/mol. Well-known is the Redfield ratios of carbon to nitrogen to phosphorus in (marine) biomass: 106: 16: 1 (mol/mol).

Nutrient use efficiency: The ratio of the nutrient in desired output (e.g. crop product) divided by the total nutrient input of a system (field, farm, technological unit, region), expressed in kg per kg or in %. In specific cases, nutrient use efficiency may be expressed also in terms of apparent recovery efficiency, plant physiological efficiency, agronomic efficiency, recovery efficiency (Dobermann, 2005).

Pollution swapping: the side-effect of a measure aimed at decreasing a specific emission to the environment: a concomitant increase of another unwanted emission. Pollution swapping may relate to the swapping to a different nutrient form (e.g. ammonia versus nitrate) or to another site/source.

[1] https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Glossary:Livestock_unit_(LSU)

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Regulatory framework: Pertains to the whole set of legal regulations, subsidies and taxes, including relevant rules, laws and regulatory bodies in a country/region.

Soil carbon balance: Change in soil carbon stock over a defined depth interval and time interval, in kg C per ha per yr. Care need to be taken that the change in soil carbon content is corrected for possible changes in bulk density during the time interval.

Soil enhancers / ameliorators: Substance that can be applied to soil to improve soil quality characteristics, but do not contain (much) nutrients, such as composts. Substances with significant amounts of nutrients would be termed bio-based fertilisers.

Soil / field nutrient balance: Nutrient input-output balance at soil-surface level, expressed in kg per ha per yr. Also called a partial soil/field nutrient balance, as the nutrient losses are not accounted for. All nutrient inputs and outputs that pass the soil surface of a field will have to be recorded, except gaseous N losses to the atmosphere. Inputs via atmospheric deposition and biological N2 fixation have to be considered. Nitrogen inputs are often corrected for NH_3 losses following application of fertilisers and manures (Net N input).

Technology readiness level: a method of estimating the technology maturity of technology. The scale consists of 9 levels. Each level characterises the progress in the development of a technology, from the idea (level 1) to the full deployment of the product in the marketplace (level 9):

Level 1 – Basic Research: basic principles are observed and reported
Level 2 – Applied Research: technology concept and/or application formulated
Level 3 – Critical function, proof of concept established
Level 4 – Laboratory testing of prototype component or process
Level 5 – Laboratory testing of integrated system
Level 6 – Prototype system verified
Level 7 – Integrated pilot system demonstrated
Level 8 – System incorporated in commercial design
Level 9 – System ready for full scale deployment
Level beyond 9 - Market introduction

2.4 Farm / agro-typologies

In the Nutri2Cycle proposal, eight agro-typologies are described, see Figure 2.3, for which innovative systems and techniques will be further developed and assessed. These agro-typologies cover the main agricultural production sectors in the EU, but the typology is not completely in line with categories from statistical sources (e.g. Eurostat) and the available farm types in the agricultural sector models. Especially for the regional and EU scale baseline determination (WP1) and impact assessments (WP4), it is important to be able to link these categories. The aim of this section is to define a standard typology that can be used throughout the project.

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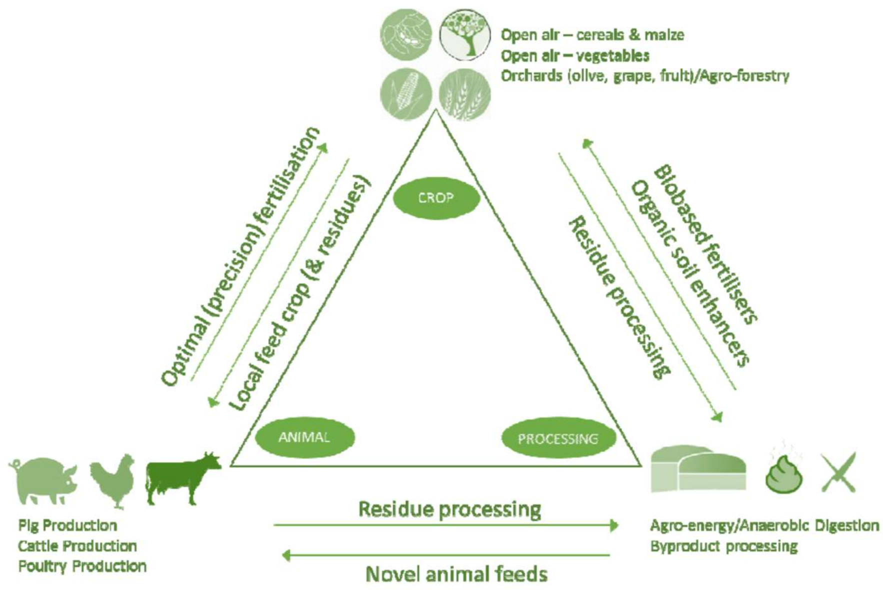

Figure 2.3. Agro-typology from Nutri2Cycle as included in the proposal

The Eurostat farm typology is available at three different levels of aggregation. The typology is also linked to the data collection for the FADN (Farm Accountancy Data Network) and the FSS (Farm Structural Survey) and is also used in the CAPRI model. The first two aggregation levels are shown in Table 1. Table 2 provides for the highest level of aggregation an overview of the number of farms, the utilized agricultural area (UAA) and number of livestock units (LSU) for each of the 9 farm typologies to illustrate the importance of each class for the different aspects.

Table 1. Eurostat Farm typology at general and principal farming type level

General Farming type		Principal farming type	
1.	Specialist field crops	15.	Specialist cereals, oilseeds and protein crops
		16.	General field cropping
2.	Specialist horticulture	21.	Specialist horticulture indoor
		22.	Specialist horticulture outdoor
		23.	Other horticulture
3.	Specialist permanent Crops	35.	Specialist vineyards
		36.	Specialist fruit and citrus fruit
		37.	Specialist olives
		38.	Various permanent crops combined
4.	Specialist grazing livestock	45.	Specialist dairying
		46.	Specialist cattle - rearing and fattening
		47.	Cattle - dairying, rearing and fattening combined
		48.	Sheep, goats and other grazing livestock
5.	Specialist granivore	51.	Specialist pigs

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General Farming type		Principal farming type	
		52.	Specialist poultry
		53.	Various granivores combined
6.	Mixed cropping[1]	61.	Mixed cropping
7.	Mixed livestock[1]	73.	Mixed livestock, mainly grazing livestock
		74.	Mixed livestock, mainly granivores
8.	Mixed crops-livestock	83.	Field crops - grazing livestock combined
		84.	Various crops and livestock combined
9.	Non classifiable		

[1] Mixed farming types refers to farms that have multiple main crop or livestock activities

Table 2. Eurostat Farm type and the number of holdings, utilized agricultural area (UAA) and livestock unit (LSU) numbers for the EU based on the Farm Structure Survey of 2013

Farm type	Holdings	UAA (ha)	Livestock	Holdings	UAA	LSU
	number	ha	LSU	% of total	% of total	% of total
Specialist field crops	3200460	74139320	2650310	29.5	42.5	2.0
Specialist horticulture	210190	1195470	123000	1.9	0.7	0.1
Specialist permanent Crops	1894590	10684700	257390	17.5	6.1	0.2
Specialist grazing livestock	1855620	54767770	62168500	17.1	31.4	47.8
Specialist granivore	1020340	4174540	44086050	9.4	2.4	33.9
Mixed cropping	520470	4811930	487440	4.8	2.8	0.4
Mixed livestock	477250	4051880	7052500	4.4	2.3	5.4
Mixed crops-livestock	1499910	19892660	13346840	13.8	11.4	10.3
Non classifiable	159460	895360	0	1.5	0.5	0.0

In Table 3 we linked the Eurostat farm types to the agro-typologies from the Nutri2Cycle proposal and provide a proposal for the final farm typology to be used in the assessments in Nutri2Cycle. We propose to use six main farm types, which can be directly linked to the Eurostat farm typology for the modelling at regional scale. This selection is also based on the first selection of the longlist of innovative systems and techniques that was discussed on the bootcamp meeting in Brussels on the 21st of January 2019. The six main farm types are field crop farms, permanent crop farms, dairy farms, pig farms, poultry farms and mixed crop livestock farms. Together these 6 farm types cover 73% of all farms, 73% of all UAA and 67% of all LSU in the EU. If cattle rearing and fattening would be included as well, these percentages would increase to 77%, 82% and 80% respectively.

Cattle rearing and fattening is often in more extensive systems, with grazing and little use of external feed sources. Most of the proposed innovations are not very relevant in that case, and in the current proposed innovations, no beef farms are included. Horticulture is also not included, since it comprises only a small area of the total UAA, and no horticulture specific innovations have been proposed. Furthermore, there might be problems to model emissions for these often very diverse and more specific crops.

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For anaerobic digestion and other processing technologies of agro-residues, it would be better to include these as techniques rather than a farm typology, at least for the regional scale modelling, as it is not linked to the Eurostat farm types. Although for anaerobic digestion, quite a good coverage and availability of data is expected through EBA and other sources, the anaerobic digestion technique itself is not very prominent present in the preselection of innovations from the bootcamp meeting.

Table 3. Final selected farm typology (last column) for Nutri2Cycle based on the Eurostat farm types and the agro-typology mentioned in the Nutri2Cycle proposal

Eurostat farm type	Agro-typologies original proposal	Final selected farm typology
Specialist field crops	Open air – cereals & maize	Specialist field crops
Specialist horticulture	Open air – vegetables	
Specialist permanent Crops	Orchards	Specialist permanent crops
Specialist grazing livestock	Cattle production	Specialist dairying
Specialist granivore	Pig production	Specialist pigs
	Poultry production	Specialist poultry
Mixed cropping		
Mixed livestock		
Mixed crops-livestock		Mixed crops-livestock
Non classifiable		
	Anaerobic digestion	
	By-product processing	

2.5 Indicators

In Task 1.5 of the Nutri2Cycle project different indicators were reviewed and a manageable set of indicators relevant for Nutri2Cycle was developed. This work has been described in Deliverable 1.1 “Report on indicators set for comparison and benchmarking”. For the review the following indicator typology was used: i) agronomic indicators; ii) emission-resource based indicators; iii) environmental indicators; iv) economic indicators and v) social indicators.

For environmental indicators the indicators are based on the guidance of the Product Environmental Footprint (PEF). From all impact categories climate change, acidification, eutrophication and fossil resource depletion were selected as the most relevant impact categories related to C, N and P flows, which is the focus of the Nutri2Cycle solutions. Each impact category is linked to one or more specific emission or resource indicator (Table 4).

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Table 4. Selected impact categories and related indicators that will be used to assess the environmental impact of the solutions in Nutri2Cycle

Impact category	Indicators	Aspect covered
Use of primary resources	Phosphate ore	Rock phosphate used to produce P fertilizers
	Natural gas	Natural gas avoided by nutrients recovery
	Oil	Crude oil used to produce P fertilizers
	Energy	Energy consumption in agriculture
	Water	Water consumption
	Nutrients recovered	N and P recovered from agricultural practices
Acidification	Ammonia, NH_3 (air emission)	Ammonia emitted to the air from agricultural practices
Eutrophication	Nitrates (water emission)	Nitrate leached in the water from agricultural practices
	Phosphorus (water emission)	Phosphorus leached in the water from agricultural practices
Climate change	Dinitrogen monoxide, N_2O (air emission)	N_2O emitted to the air from agricultural practices
	Methane, CH_4 (air emission)	Methane emitted to the air from agricultural practices
	Effective soil organic matter	Organic matter input that is still available one year after incorporation in the soil
	Carbon footprint	Carbon footprint

The main economic indicator for assessment of individual solutions is the effect on the farmer's income, which depends on a range of other economic indicators, such as revenue, prices, cost of inputs and subsidies. For the modelling at European scale in WP4 also effects on macroeconomic indicators such as GDP and changes in land use will be considered. Social indicators are still at a preliminary stage of development with no consensual approach and lack of databases to assess some of the categories. Nutri2Cycle will work on further development of social indicators for assessments in agricultural projects, with special attention on consumer acceptance of new technologies (WP5). For the final evaluation and ranking of the solutions the Nutri2Cycle project will make use of Multi-criteria decision analysis (MCDA) (Task 3.4). MCDA is a widely used method within the frame of natural resource management, where multiple indicators or factors should be considered.

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2.6 Collection and selection of solutions

In the Nutri2Cycle project a range of solutions for closing CNP cycles in agriculture are investigated and demonstrated. The project started with the collection of a longlist of proposed technical and management solutions for farming systems aimed at closing nutrient loops and efficient mitigation measures. This list of solutions was based on a bottom-up approach where solutions were acquired through partner and stakeholder collaboration, including via EIP-AGRI Operational Groups. In the so-called innovation funnel in WP2 a further selection of the solutions has been made to come to a manageable number of solutions that will further investigated, included in the impact assessment (WP3 and 4) and demonstrated (WP6). This selection process is schematically presented in Figure 2.4.

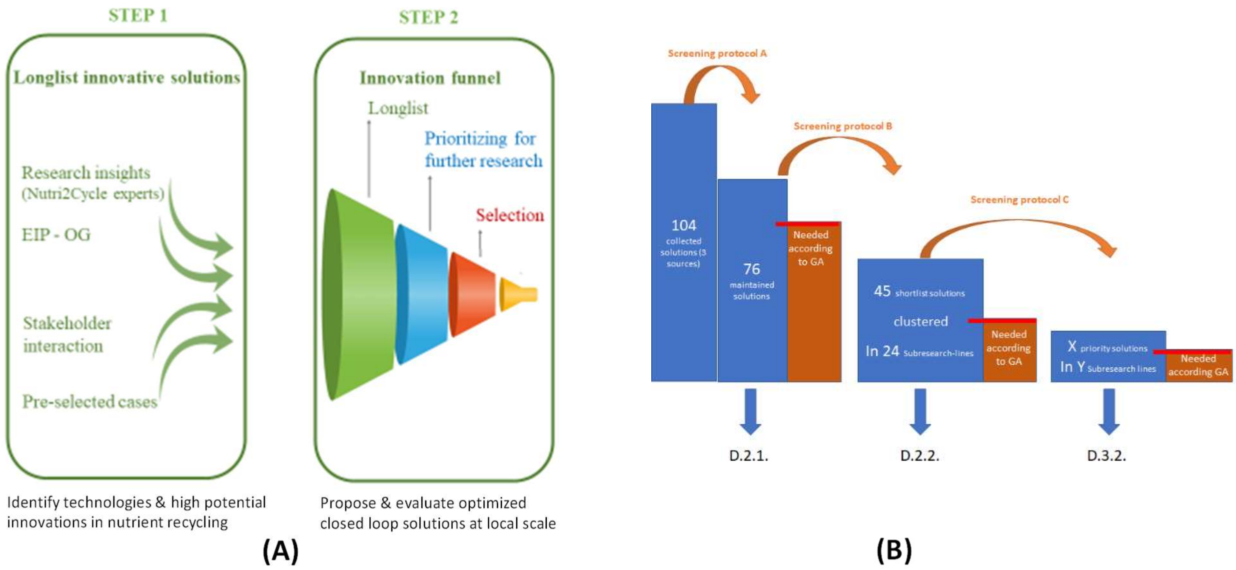

Figure 2.4. Schematic procedure for selection of the priority solutions in the Nutri2Cycle project: (A) Collection & & Selection process as illustrated the Grant Agreement, (B) Practical link to project Deliverables.

At the start of the project in total 104 different solutions were proposed. Based on **Screening protocol A** the selection of the solutions for the longlist was made, based on the following criteria:

- the potential to address effective closing of CNP loops and the capacity to address specific local environmental constraints (nitrate vulnerable zone, excess nutrients, organic matter scarcity and soil quality) ;
- solutions need to address one or more of the selected agro-typologies in Nutri2Cycle;
- solutions should be widely adoptable, covering a wide geographical areas in the EU;
- the potential innovation beyond the current state-of-play (innovation in technology, management and business model);
- the environmental potential of the solutions;
- the research capacity and competence of partners and data availability;
- the availability (now or in the future) of economic data;

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- the willingness to share data and/or agro-technical insights, working together with the consortium on the proposed solution.

Based on this screening, 28 of the 104 proposed solutions were discarded due to insufficient available data provided or insufficiently linked to the scope of Nutri2Cycle. The remaining 76 solutions have been described in Deliverable 2.1.

In the innovation funnel a further evaluation and prioritisation of the longlist solutions was made. According to the Grant Agreement (GA) this selection should be based on the ability and potential to close N, P and C loops and their technological, environmental and economical validity. However, as this selection already had to be made by month 6, the required data on the solutions to make this assessment was still incomplete. Therefore, an alternative shortlisting procedure (**Screening protocol B**) was used, which was based on the following criteria:

- A Pivotal Project Launch & Decision Bootcamp in Brussels on 21/01/2019 was organized with detailed partner discussion on the longlist (potential towards enhancing GHG footprint, reduce N and P losses, and/or improve soil organic carbon). This boot camp was a full physical gathering of the Nutri2cycle consortium, linked as a dedicated satellite event to the first Edition of the "European Sustainable Nutrient Initiative" conference (ESNI);
- Interlinkage with the different identified agro-typologies and investigated research lines within Nutri2Cycle;
- Expert assessment on availability and quality of existing data (e.g. building on previous projects) and access to infrastructure (research scalability / potential towards TRL-lift within the project time) to carry out further investigations of the proposed innovation in relevant conditions;
- A balanced geographic spread, as well as sufficient coverage of the 8 agro-typologies

This resulted in the selection of 45 of the longlist solutions, which were clustered into 24 sub-research lines, which has been described in Deliverable 2.2. The strategy to work around 24 sub-research lines is another rationalisation in the selection and categorization process: rather than identify 24 loose and independent solutions the consortium chooses to pursue investigations along 45 of the original long-listed solutions but to cluster them into workable categories which themselves link to the 5 over-arching research lines. Essentially, the selection and categorization of solutions therefore follows the following "taxonomy": 5 research lines > 24 sub-research Lines > 45 single investigations.

This shortlist of solutions formed the basis for the feasibility assessment for the emission modelling and the LCA selection. For these shortlisted solutions data was acquired from the agro-technical research in WP2, which has been described in Deliverables 2.3 and 2.4. These Deliverables contain an elaborated description expanding beyond the description of the original Factsheets compiled in D.2.1. In addition, the consortium will commit to gather further quantified data from the agro-technical research (WP2) of which the results will be compiled in a new Deliverable 2.6. (not originally foreseen in the Grant Agreement) more towards the end of the project.

In the Grant Agreement is stated that from the Shortlist, at least 12 solutions will be prioritized for demonstration purposes (WP6) and detailed impact assessment (WP3), including LCA, Social LCA and

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Cost Benefit Analysis (CBA). This selection is based on **Screening protocol C** using a Venn diagram approach, in which solutions were scored across three dimensions:

C1. Potential availability of background information & documentation related to environmental analysis (in order to be able to make reliable LCA assessment),
C2. Within N2C consortium agrotechnical expertise, competence and research capacity,
C3. Potential for scalability and demonstration of proposed solution within the project duration.

The approach positioned all investigations from the Shortlist and placed them on a Venn-diagram in which solutions which scored positive on all three dimensions are placed in the centre of the Venn-diagram, those that score positive according to two dimensions are placed in between both of them and those that only score for one dimension are only placed in part of the Venn-diagram exclusively. For each of the three dimensions, a dedicated survey & analysis were performed.

For dimension C1, a “traffic light” study was carried out by UCPH in which the feasibility of each shortlisted solution for subsequent modelling and/or LCA analysis was scored using a green-orange-red light system indicating positive (green), negative (red), or expected problems/limitations (orange). Each shortlisted solution was reviewed by Daisy, SWAP-ANIMO, and MITERRA-Farm modellers to assess its feasibility to be simulated by each model. The assessment took into account model capability, assumptions that must be made, Technology Readiness Level (TRL), and potential data availability by M16 (tier 1) and M20 (tier 2). Following that, the solutions were also screened by LCA partners to select their preferred cases for LCA, considering both the scientific merit, and data availability from modelling and technology owners. The selection process also aimed to distribute the selected LCA cases among the 5 research lines as well as partner countries. Finally, the overall feasibility for each shortlisted solution was scored by combining the two assessments.

For dimension C2, a survey was carried out by Ghent University in which the consortium was probed for active expertise and capacity – both in human resources (PhD, postdocs, PIs) and research infrastructure to address the solutions. For dimension C3, a mapping exercise was carried out by Teagasc in which the pilot & demonstration capacity on each of the solutions was evaluated, which combined both ‘scalability’ of solutions within the project lifetime as well as the infrastructure at hand allowing a TRL-lift within and by the project.

The outcome of the Venn-diagram investigation, converging the three abovementioned studies into one Venn-diagram comparison was presented at the midterm partner meeting in February 2021. The ensuing discussion that emerged from that analysis resulted in the prioritization, bearing in mind the following criteria:

- Solutions scoring positive in two or three of the Dimensions (C1-2-3) deserve priority based on the alignment between agro-technical capacity, environmental data & infrastructure availability/suitability.
- In the discussion further scrutiny was needed and applied in order to further streamline the number of retained solutions to add focus in the project. For the consortium was guided by the following key questions:
  1) are all 5 research lines sufficiently represented in the final list of priority solutions?

2) do we expect good accessibility and willingness-to-share of economic data so that abovementioned studies can be expanded with the full (required) economic assessment on the final solutions?
3) from which of the solutions do we expect most/least direct impact on closing NPC cycles within the project lifetime?

In addition to the priority listing, at the midterm partner meeting it was confirmed that ongoing investigations and communications which are NOT on the final priority list, themselves do not need to end or be discarded. The priority list implies further scrutiny, prioritization, alignment and focus but Nutri2Cycle will continue to also support the other originally (short-)listed solutions. Nonetheless the priority for environmental, agro-technical, economic, social investigation will be placed on the selected priority.

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3. Modelling protocol for CNP flows and stocks

3.1 Introduction

The aim of the modelling task is to quantify emissions at different spatial scales (field, farm, region) related to C, N and P flows and to make an assessment of environmental impacts of innovations. Models are provided with data on physical conditions, data describing the agricultural practice and data on the implementation of innovations and measures. To structure this data:

- A unified template for basic (raw) data will be provided, specifying the type of variables and the respective units.
- A database is set up where the relevant data for the modelling tasks is collected. Part of the model data and coefficients are derived from existing modelling systems (CAPRI, MITERRA-Europe) and databases (e.g. EUROSTAT)

Both actions will be further elaborated as part of the work under Task 1.2, where the baseline of CNP flows in European farming systems will be determined and analysed. Different types of models are used for different spatial scale levels:

- Field level: deterministic process models that describe detailed nutrient flows in crop and soil (SWAP-ANIMO; DAISY)
- Farm scale: a model for quantifying C, N and P flows on a farm, or a cooperation of different farms. The description includes both animal production and plant production (MITERRA-FARM)
- Regional Scale (EU): a model for quantifying C, N and P flows in EU regions. Also, for this model holds that the description includes both animal production and plant production (MITERRA-Europe; CAPRI)

Results of the models, expressing the change of emissions as a result of innovations relative to the emissions as they occur in a baseline scenario, are processed into key figures that are recognizable for practice and policy. These results are used to calculate impacts. Different techniques will be used for both the quantification of emissions and the calculation of impacts, including life cycle assessment (LCA). The general scheme of information flows is depicted in Figure 3.1.

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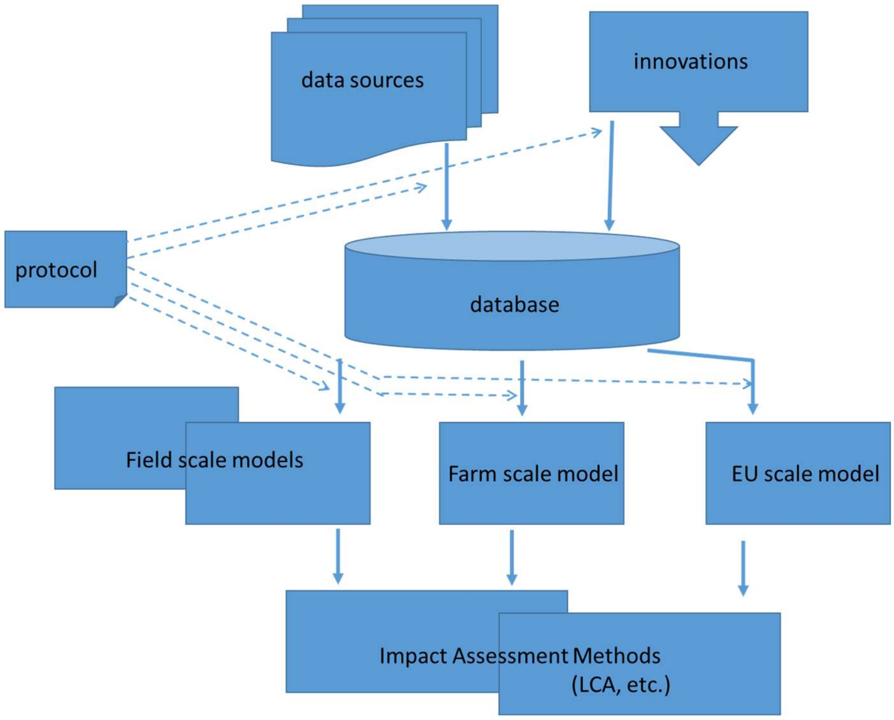

Figure 3.1 Scheme of information flows to perform environmental impact assessments of innovations

3.2 Modelling scales and system boundaries

The definition of CNP flows, and the relevant processes to consider, depend on the spatial scale. Within the Nutri2Cycle project, we consider the farm scale as the most concise for understanding the CNP flows involved in the interactions between crop production, animal production and the role of processing installations, and the regional (EU) scale for the translation into policy decisions.

The system boundaries for the impact assessment at the farm scale are defined by:

- Farm gate
- Air
- Root zone depth, from where the loss fluxes can contaminate groundwater and / or surface water. In cases of shallow groundwater levels, the root zone could be chosen as a system boundary. In case surface water system are visible within the field, these surfaces waters (tile drains; ponds; small streams) can be considered as a system boundary.

The establishment of system boundaries depends on a number of factors, among which landscape soil and water system are important physical factors and should accounted for in each case study. At the farm scale a number of components are potentially involved in the environmental impact assessment (Table 5).

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Table 5. Relevant compartments and their specific (emission) components for the environmental assessments

Compartment		Component	Remarks
Emissions to air	C	CO_2; CH_4	Mass flux
	N	NH_3; N_2O; NOx	Mass flux
Emissions to groundwater	C	DOC	Mass flux
	N	NO_3	Mass flux
	P	PO_4	Mass flux
Emissions to surface waters	C	DOC	Mass flux
	N	N-total; DIN; DON; NO_3	Mass flux
	P	P-total; PO_4; DOP; particulate-P	Mass flux
Soil quality status	C	Changes in soil organic carbon	Weight content; provide reference depth
	N	Changes of C/N ratio	Ratio of organic bounded C and organic bounded N ; provide reference depth
	P	Changes of Total P-content, P ox extractable; soil P-status	Provide definition of soil P-status used; provide reference depth

The database should contain records relating to each CNP flow:

- stoichiometric definition (e.g. NO_3 or NO_3-N)
- spatial aggregation level (e.g. based on summation of fields)
- temporal aggregation level (e.g. summation of daily fluxes; based on long term key indicator values)
- unit of mass, area and time (e.g. kg ha^{-1} yr^{-1})

A number of models have been proposed to conduct parts of the emission calculations. Table 6 provides an overview with respect to their capabilities. Impact modelling is performed by LCA models, and at regional scale partially by CAPRI and MITERRA-Europe.

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Table 6. Overview of emissions and emitted components that can be assessed by the different models

Compartment		Component	Field scale		Farm scale	Regional scale	
			SWAP-ANIMO	DAISY	MITERRA-FARM	CAPRI	MITERRA-Europe
Emissions to air	C	CO_2; CH_4	+[1]	+[3]	+	+	+
	N	NH_3; N_2O; NOx	+	+	+	+	+
Emissions to groundwater	C	DOC	+	+			(+)
	N	NO_3	+	+	+	(+)	+
	P	PO_4	+		(+)		
Emissions to surface waters	C	DOC	+	+			(+)
	N	N-total; DIN; DON; NO_3	+	+	(+)		+
	P	P-total; PO_4; DOP; particulate-P	+[2]				
Soil quality status	C	Changes in SOC	+	+	+		+
	N	Changes of C/N ratio	+	+	(+)		(+)
	P	Changes of Total P-content, P ox extractable; soil P-status	+		+		+

[1] CH_4 emission only for special cases

[2] particulate P transport not included yet

[3] not CH_4

3.3 Model descriptions

SWAP-ANIMO

The ANIMO model (Groenendijk et al., 2005, 2014) derives its hydrological input information from the sequentially coupled SWAP model. SWAP simulates water flow in the soil – plant – atmosphere domain in an integrated manner. The ANIMO model quantifies the relation between fertiliser application rate, soil management and the emissions of carbon components, nitrogen and phosphorus to air, groundwater and surface water systems (Figure 3.2). The upper boundary of the model is the agricultural land surface, where nutrients are applied, the side boundary is the edge of the field, where N and P leach from soil to ditch. The lower boundary is defined at a hydrological boundary in the groundwater. ANIMO includes complete descriptions of the organic matter, nitrogen and phosphors cycle since these cycles are interrelated in farming systems and in soil biochemistry. The ANIMO model is used for the evaluation of fertiliser policy measures in the Netherlands (Wolf et al., 2003) and has been reviewed and compared with other European models for several aspects, such as the organic matter and N cycle (Wu and McGechan, 1998), and the P cycle (Lewis and McGechan, 2002).

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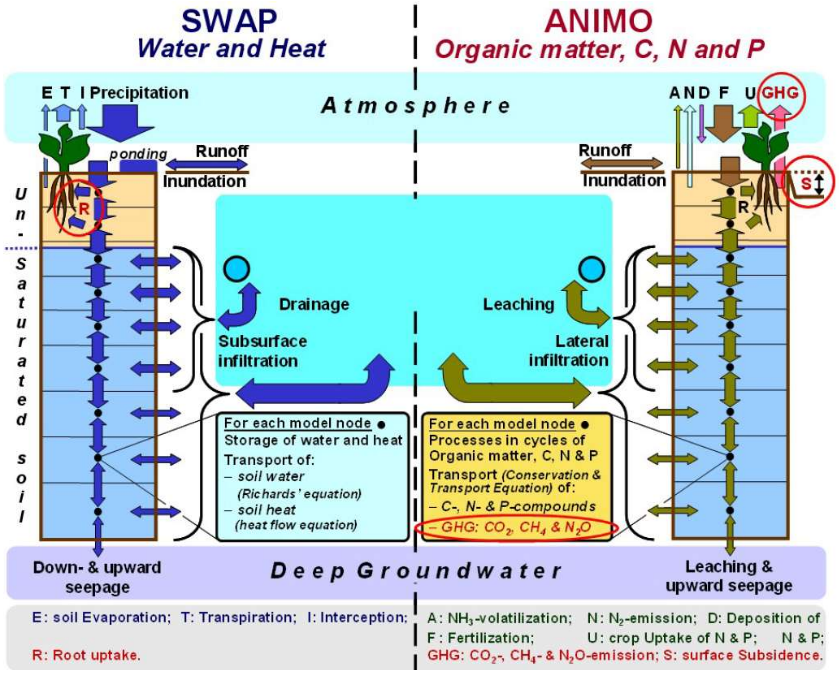

Figure 3.2. Schematic overview of processes simulated by the sequentially coupled SWAP-ANIMO model

DAISY

The Daisy model (Hansen et al., 2012) is a soil-plant-atmosphere system model focusing on agro-ecosystems and can be characterized as an explanatory, mechanistic model. It simulates water, heat, carbon, and nitrogen balances as well as crop production and pesticide fate in agro-ecosystems subjected to various management strategies. The basic scale of application is the field (management unit), which may be simulated in one or two dimensions. Daisy allows several different process descriptions for water flow, evapotranspiration, crop growth, and solute transport, depending on objective of study and available data. All applications require information concerning weather (daily values of solar radiation, air temperature, precipitation), soil (texture, organic matter, hydraulic parameters, etc.), location of groundwater, crop rotation, tillage, use of mineral and organic fertilizers (incl. manures, digestates etc.), irrigation, sowing, harvesting, and organic matter turnover in the soil. Daisy was first developed in early 1990ies (Hansen et al., 1991), but has been continuously developed, expanded (Abrahamsen et al., 2000) and validated in numerous international comparative studies (see Hansen et al., 2012 for more details). Currently (January 2019) the most recent model version is no. 5.73 (https://daisy.ku.dk/), and the model has been applied in more than 150 studies published in peer-reviewed journal papers.

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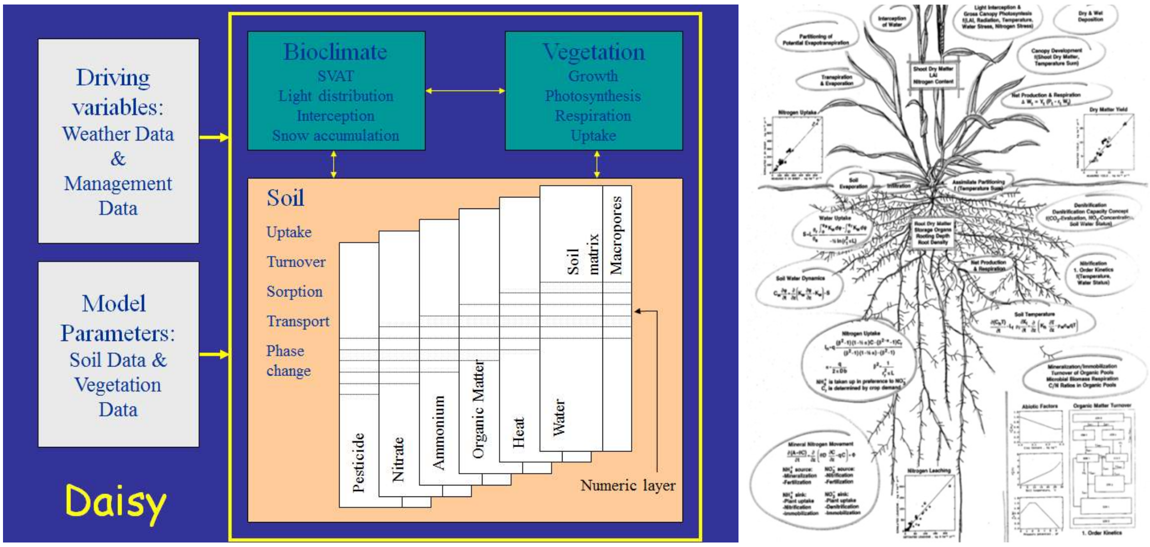

Figure 3.3. Schematic overview of components and processes simulated by the Daisy model and necessary parameters and driving variables

MITERRA-Farm

MITERRA-Farm is a farm scale version of the MITERRA model, which will be developed within the Nutri2Cycle project, as it can be easily adapted to function at different scale levels. Previously, already a Dutch version of the model was created from the original MITERRA-Europe model. MITERRA-Farm will be an emission factor based model, that can integrate all farm CNP flows, both from livestock and crop production. The model will make use of available international guidance, such as the IPCC Guidelines for greenhouse gas emissions, the guidance document of the UNECE-TFRN for establishing N budgets and the EMEP/EEA guidebook for NH_3 emission accounting. Specific emission factors for the innovative techniques can also be derived from the detailed process-based field models (SWAP-ANIMO, DAISY). The model will calculate all CNP flows, emissions to air and water and changes in CNP stocks for both livestock and crop based farms. The model will make use of the database of MITERRA-Europe for climate data and country specific emission factors and parameters.

MITERRA-Europe

MITERRA-Europe is a deterministic environmental assessment model, which calculates greenhouse gas (CO_2, CH_4 and N_2O) emissions, soil organic carbon stock changes and nitrogen emissions (N_2O, NH_3, NO_x and NO_3) on annual basis, using emission and leaching fractions. The model was developed to assess the effects and interactions of policies and measures in agriculture on N losses on a NUTS-2 (Nomenclature of Territorial Units for Statistics) level in the EU-28 (Velthof et al., 2009; de Vries et al., 2011). Input data consist of activity data (e.g., livestock numbers and crop areas and yield from Eurostat and FAO), spatial environmental data (e.g., soil and climate data) and emission factors (IPCC and GAINS). For soil carbon the calculation rules of the well-known soil carbon model RothC are used. The model includes measures to simulate carbon sequestration and mitigation of GHG and NH_3 emissions and NO_3 leaching. The model can also assess all GHG and nitrogen emissions following a LCA approach until the farm-gate (Lesschen et al., 2011). Effects of mitigation policies and measures

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can be assessed, as are long-term scenarios, based on activity inputs from other economic models (e.g. CAPRI).

CAPRI

The CAPRI model (Britz and Witzke, 2014) is a comparative static partial equilibrium model for the agricultural sector. The main objective is to evaluate ex-ante impacts of the Common Agricultural Policy and trade policies on production, income, markets, trade, and the environment, from global to regional scale. It has a supply module covering the EU and some auxiliary European countries, and a market module, covering regions in the rest of the world. The supply module has one representative farm model for each NUTS2 region of the EU, or similar administrative units in auxiliary countries, amounting to about 280 regions in the model. Around 55 agricultural inputs produced in about 60 activities are covered in the supply module. Policy instruments for each region are modelled in detail, especially those in Pillar I. The models optimize regional agricultural income, given the prices for inputs and outputs, subsidy levels and other policy measures subject to different constrains (e.g. availability of land, feed and plant nutrient requirements for each region). In CAPRI environmental indicators, primarily for nutrient surpluses and greenhouse gas emissions are also calculated. Regarding nutrient surpluses, the supply module contains nutrient balance equations for nitrogen, phosphorous and potassium. It considers nutrient uptake by crops following a crop growth function, and supply of nutrients from mineral fertilizer, manure, crop residues, and, for nitrogen, atmospheric deposition and fixation. The balances also contain factors for over-fertilization, loss rates, and nutrient availability per source. From those balances nutrient surpluses can be calculated per region of the supply model. Technical information from the supply module is used to compute greenhouse gas emissions, based on IPCC methodology. Globally, greenhouse gas emissions are computed based on estimated emission intensities per ton of product and production levels for globally traded commodities.

3.4 Linkage of model results

The field scale models are especially required to simulate long term effect of organic fertilizers, dynamic effects of P and for the underpinning of N leaching and emission factors. Effects of innovations could be simulated by the models by imposing changes in inputs and model parameters (coefficients) with respect to:

- Application rate of mineral fertilizers, animal manure and other organic amendments
- Composition of mineral fertilizers, animal manure and other organic amendments
- Nitrogen and phosphorous use efficiency
- Soil tillage practices
- Land use and choice for certain crops

The two models for field scale simulations (DAISY and SWAP-ANIMO) are detailed and deterministic in nature. They are used to underpin emission factors in the farm scale model and in the regional models. At the start of the Nutri2Cycle project, it is not clear in advance for which emission factors the

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detailed models can deliver information. In order to further clarify this information, the following actions will be taken, which will be described in detail in Deliverable 1.5:

- For each model, an inventory of model inputs and outputs will be listed.
- The list of farm types (Section 4.3) will be completed, and a number of them with land based agricultural production, with an accompanying set of one or more physical geographical settings, will be selected.
- Two of the farm types selected will be used to run both the DAISY model and the SWAP-ANIMO model. The ability to alter inputs and model parameters (coefficients) and the responses on emissions will be assessed. Results will be compared and strengths and weaknesses of the models, related to the innovations proposed, will be reported.
- The final version of the interface will be established after modelling the first two farm types with DAISY and SWAP-ANIMO model and the comparison of strengths and weaknesses of the models, related to the innovations.
- On the basis of this comparison the set of farm types, with accompanying physical geographical settings and the innovations that may be relevant for the farm type, will be subdivided into a set to be simulated with DAISY and a set to be simulated with SWAP-ANIMO. Responses on emissions will be translated into changes of emissions factors of the farm scale model and the regional models.
- The interface between the field scale models and the farm scale model will be drafted.

The farm scale model will be applied to the specific situations of the farm types, mimicking the practical circumstances as realistic as possible, and uses model results (e.g. changes inputs, new emission factors) of the field scale models. The added value is that this model can calculate interactions between crop production, animal production and innovations with respect to the processing of animal manure and waste.

The regional scale models will be run with more or less averaged conditions, but require the same type of inputs as the farm scale model. The added value is that these models account for interactions between crop production, animal production and innovations at the regional scale. The methodologies and outcomes of both regional models, MITERRA-Europe and CAPRI, will be compared for the baseline year (probably 2010) and potential improvements for the models will be identified, as part of Task 1.2. Next step is to make an assessment of which innovations can be simulated with the regional models. Although both MITERRA-Europe and CAPRI can be used to assess the environmental impact of measures, it was decided at the start of Nutri2Cycle that MITERRA-Europe will focus on the environmental impact and CAPRI on the economic impact. Implementation of new measures in the CAPRI model is quite time consuming due to the multiple interactions with economic parameters, and lower flexibility of the model. MITERRA-Europe is in more flexible, as only interactions among nutrient flows have to be taken into account, which makes it easier to implement new measures. Regions and combinations of pedologic/climate zones and physical geographical settings to be considered in the regional scale modelling will be decided on in a working session with partners involved in activities described in the section on Farm/agro-typologies and the activities described in Section 4.

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4. Farm data collection protocol

4.1 Introduction

The impact assessment of the innovative systems and techniques can be done at different scales, which also requires different baseline data. Part of the solutions will affect the emissions at field level, for which the process-based models DAISY and SWAP-ANIMO will be used. The use of these models and the baselines that are developed will be described in Nutri2Cycle Deliverable 1.5. However, for other solutions that involve livestock, e.g. new protein feeds, and manure management, such as anaerobic digestion, a farm level approach is required. The farm scale is where data on CNP flows from both field and animal scale are collected and managed by the farmer. Representative farm level data is required for the baseline assessment of CNP flows against which the innovations can be assessed. However, farm level data is often not publicly available, and in statistical surveys like the Farm Accountancy Data Network and the Farm Structure Survey, no or incomplete information is collected on CNP flows. On the other hand, most farmers will have that kind of information, and in some countries there are data collection systems especially aimed at collecting and assessing nutrient flows to comply with national fertilization policies, e.g. the Annual Nutrient Cycling Assessment (ANCA) in the Netherlands.

At the kick-off meeting in Ghent, it was therefore decided to start a data collection of CNP flows at farms to create a baseline data set for the impact assessment, for which the MITERRA-Farm model will be used. This model, based on the MITERRA-Europe model is an emission factor based model, which requires less detailed data compared to the process based models DAISY and SWAP-ANIMO that will be used for the field level emission modelling. The data requirements are therefore lower and more in line with the kind of data that is available in farm management software. This work will be part of Task 1.2 (Analysis and assessment of baseline CNP flows in main farming systems in Europe). The objective of this section is to establish a protocol for guidance on the data collection of CNP flow data at farms.

4.2 Variables for data collection

In this section an overview is provided of the type of farm data that should be collected for the baseline analysis at farm level in WP1. This is to assure Nutri2Cycle partners have a clear understanding of the kind of data that is required. *Figure 4.1. Schematic overview of the main inputs and outputs at farm scale for crop and livestock production and the processing installations. The numbers of the flows are also used in* Figure 4.1 provides a schematic overview of the inputs and output for crop and livestock production and the processing installations. These inputs and outputs can be converted to CNP flows using either default nutrient and carbon contents or farm specific contents for some flows, e.g. manure. Depending on the type of farm, the relevant flows can be identified and data for these flows should be collected. Ideally, all CNP inputs and CNP outputs of a farm are recorded over a one year period. Environmental losses are normally not monitored at farms and will be determined later by the different emission models.

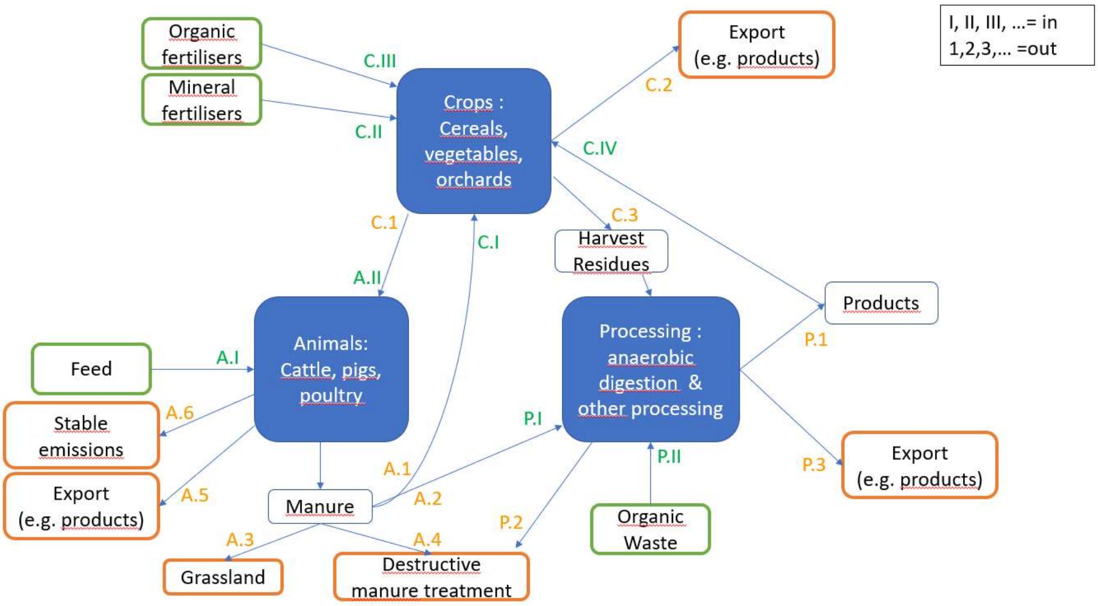

Figure 4.1. Schematic overview of the main inputs and outputs at farm scale for crop and livestock production and the processing installations. The numbers of the flows are also used in Table 7.

The numbers of the flows in Figure 4.1 are also used in Table 7, where a more detailed list of variables that should be collected is provided, and indicating for which farm types these are relevant. Besides these flow data, which are often expressed in ton fresh matter (FM) also data on the content of these materials is required. Often this is data a farmer does not have, in which case default values based on literature will be used. However, for some flows, such as for processed manure, it is important to collect the nutrient contents, as these values can vary a lot depending on the type of processing. The main information, which is often not available from the statistical surveys, is on the type and amount of manure and mineral fertilizer that is applied. Processing installations are included in the table, but at this stage it is unclear whether data will be collected for a large number of these installations, as they are not part of the selected farm types, but for some of the innovations related to manure and agro-residue processing, detailed data will be collected as part of WP2.

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Table 7. Type of variables that should be collected for the different farm types, the code flows refer to the flows illustrated in Figure 4.1 (amounts refer to fresh matter)

	Variables	Code flow	Units	Livestock farms	Crop farms	Processing installations
LIVESTOCK						
	Number of animals on farm		#	x		
	Purchased animals	A.5	#	x		
	Livestock products		ton/y			
	Animal feed (type and amount)	A.I, A.II, C1	ton/y	x		
	Type of stable + emissions if available	A.6		x		
CROPS						
	Crops harvested		ton/y		x	
	Amount of arable land		ha		x	
	(+ Crop type, rotation, etc.)					
	Crop / Harvest residues	C.3	ton/y		x	
PROCESSING						
	Processed volume (input)		ton/y		x	x
	Other input to process	P.II	type			x
	(e.g. organic waste, harvest residues)	P.III	ton/y			
	Products produced	P.1 P.3	ton/y			x
MANURE PRODUCTION						
	Manure storage type and volume		m^3	x		
	Raw manure (slurry)		ton/y	x		
	Liquid fraction manure		ton/y	x		
	Solid fraction manure		ton/y	x		
	Stable manure (with straw)		ton/y	x		
MANURE APPLICATION / PROCESSING						
	Raw manure (slurry)	A.1, C.I	ton/y	x	x	
		A.2, P.I	ton/ha			x
		A.3	ton/ha	x		
		A.4				x
	Liquid fraction manure	A.1, C.I	ton/y	x	x	
		A.2, P.I	ton/ha			x
		A.3		x		
		A.4				x
	Solid fraction manure	A.1, C.I	ton/y	x	x	
		A.2, P.I	ton/ha			x
	Stable manure (with straw)	A.1, C.I	ton/y	x	x	
		A.2, P.I	ton/ha			x
PROCESSED PRODUCTS APPLICATION						
	Different types of digestate products	P.1, C.IV	ton/y			x
			ton/ha	x	x	
	Different types of processing products (compost, biochar, etc.)	P.1, C.IV	ton/y			x
			ton/ha	x	x	
FERTILIZER APPLICATION						
	Different types of mineral fertilizers	C.II	ton / ha	x	x	
	Different types of organic fertilizers	C.III	ton / ha	x	x	

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4.3 Selection of farms

The selection of farms for which farm level data on CNP flows will be collected is a critical point. However, at this stage, just after the start of the project a final selection cannot be made yet, as there is no final selection yet of the 24 innovative systems and techniques, and we don't have sufficient insight yet in the availability of potential data sources at farm level in the different countries. Nevertheless, this protocol will describe the steps that are required to come to the selection of farms in the coming months.

The following steps are proposed:

1. For each EU member state with a Nutri2Cycle partner, a short inventory will be made on the availability of national systems for data collection on CNP flows at farms, e.g. in the Netherlands all dairy farmers have to fill in the Annual Nutrient Cycling Assessment tool to assess.
2. Based on the preliminary selection of the 24 innovations, an assessment will be made for which farm types data should be collected, and in which countries these farm types are relevant, e.g. innovations related to orchards are most relevant for the Mediterranean countries.
3. A data collection format will be developed to ensure harmonised data collection on the relevant variables, as described in Section 3.2.
4. In case a data collection system of farm level CNP flows is available in a country, we will try to get access to these data for a selection of farms.
5. In case such data set is not available, the WP1 partners with capacity to collect farm level data, will for their country start a data collection for a selection of farms. This can be linked to existing data structures (e.g. FADN) where additional information is required, which will be obtained by interviews with the farmers, either via farm visit or telephone calls.
6. The collected data will be checked and harmonised if required, and will be stored in a central database, where data is available for further analysis and (modelling) assessments.

As the main objective of the farm data collection is for the establishment of a baseline (WP1), against which the innovative systems and techniques from WP2 will be assessed (in WP3), it is important to give a representative picture of agriculture. Selection criteria will comprise the following aspects: relevant farm type, capacity available with Nutri2Cycle partners to collect farm level data, geographic spread, farm scale and soil types. In Table 8 an example is provided how some of these criteria can be used to derive the relevant farms that should be included in the data collection. In addition, other aspects such as level of innovation and cooperation with other farmers, stakeholders and the scientific environment, might be relevant for the final selection.

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Table 8. Example table for selection of farms for data collection with some first selection criteria for Flanders

	Pig	Cattle	Poultry	Cereals and maize	Vegetables
Farm scale	> 2000 animals	> 60 animals	> 30000 animals	> 20 ha	> 10ha
Farm type	Intensive,	Dairy	Intensive,	Cereals	
	Mixed	Intensive,	Mixed		
		Mixed			
Soil type					
Climate zone					
Number of farms					

4.4 Data acquisition, storage and accessibility

The farm level data that will be collected in WP1 will be centrally stored in a database on a password-protected server, that is only accessible to the relevant project partners that will use the data in their analysis and assessments. The individual farm data will never be presented as such, but only in aggregated forms, and will not be able to trace back to the location and name of the farmer. The data will only be used for the Nutri2Cycle project, unless permission is provided by the farmer to use the data also for other projects. (see data management plan Deliverable 8.2).

5. References

Abrahamsen, P., and S. Hansen. 2000. Daisy: An open soil-crop-atmosphere system model. Environ. Model. Software 15(3): 313-330

Britz, W. and P. Witzke [Eds.] (2014). CAPRI model documentation 2014. University of Bonn, Bonn, 277 pp. Available at http://www.capri-model.org/docs/capri_documentation.pdf.

Coppens, J., Meers, E., Boon, N., Buysse, J., & Vlaeminck, S.E. 2016. Follow the N and P road: High-resolution nutrient flow analysis of the Flanders region as precursor for sustainable resource management. Resources, Conservation and Recycling, 115, 9-21.

de Vries, W., Leip, A., Reinds, G.J., Kros, J., Lesschen, J.P., Bouwman, A.F. 2011. Comparison of land nitrogen budgets for European agriculture by various modelling approaches. Environmental Pollution, 159: 3254-3268.

EU Nitrogen Expert Panel (2015) Nitrogen Use Efficiency (NUE) - an indicator for the utilization of nitrogen in agriculture and food systems. WUR, Wageningen, Netherlands.

Groenendijk, P., L.V. Renaud and J. Roelsma, 2005. Prediction of Nitrogen and Phosphorus leaching to groundwater and surface waters; Process descriptions of the Animo4.0 model. Wageningen, Alterra–Report 983, 114 pp. https://library.wur.nl/WebQuery/wurpubs/fulltext/35121

Groenendijk, P., Marius Heinen, Gernot Klammler, Johann Fank, Hans Kupfersberger, Vassilios Pisinaras, Alexandra Gemitzi, Salvador Peña-Haro, Alberto García-Prats, Manuel Pulido-Velazquez, Alessia Perego, Marco Acutis, Marco Trevisan. 2014. Performance assessment of nitrate leaching models for highly vulnerable soils used in low-input farming based on lysimeter data, Science of The Total Environment, Volume 499, Pages 463-480. https://doi.org/10.1016/j.scitotenv.2014.07.002

Hansen, S., H. E. Jensen, N. E. Nielsen and, H. Svendsen. 1991. Simulation of nitrogen dynamics and biomass production in winter wheat using the Danish simulation model Daisy. Fert. Res. 27(2-3): 245-259.

Hansen, S.., Abrahamsen, P., Petersen, C.T., Styczen M. 2012. Daisy: Model use, calibration, and validation. Trans. ASABE 55(4), 1315-1333.

Lesschen, J.P. , Van den Berg, M., Westhoek, H.J., Witzke, H.P., Oenema, O. 2011. Greenhouse gas emission profiles of European livestock sectors. Animal Feed Science & Technology, 166-167: 16-28.

Lewis D.R. and M. B. McGechan, 2002. A Review of Field Scale Phosphorus Dynamics Models. Biosystems Engineering 82, 359–380.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under gran agreement No 773682.

Ma, L., Ma, W. Q., Velthof, G. L., Wang, F. H., Qin, W., Zhang, F. S., & Oenema, O. 2010. Modeling nutrient flows in the food chain of China. Journal of Environmental Quality, 39(4), 1279-1289. doi:10.2134/jeq2009.0403

van Dijk, K. C., Lesschen, J. P., & Oenema, O. 2016. Phosphorus flows and balances of the European Union Member States. Science of The Total Environment, 542, 1078-1093.

Velthof, G.L., Oudendag, D., Witzke, H.P., Asman, W.A.H., Klimont, Z., Oenema, O. 2009. Integrated assessment of nitrogen emissions from agriculture in EU-27 using MITERRA-EUROPE. J. Environ. Qual. 38, 402-417.

Wolf J., A.H.W. Beusen, P. Groenendijk, T. Kroon, R. Rötter and H. van Zeijts. 2003. The integrated modeling system STONE for calculating nutrient emissions from agriculture in the Netherlands. Environmental Modelling & Software 18, 597–617.

Wu, L. and M. B. McGechan. 1998. A Review of Carbon and Nitrogen Processes in Four Soil Nitrogen Dynamics Models. J. Agric. Engineering Res. 69, 279-305.