Nutri2Cycle

D.1.1 Report on indicator set for comparison and benchmarking

Deliverable: Report on indicator set for comparison and benchmarking

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Executive Summary

The Nutri2Cycle project aims to test and demonstrate the feasibility and sustainability of alternative technologies and management procedures for closing nutrient cycle in agriculture. Easily understandable and scientifically robust sustainability indicators of technology performance are required to make informed prioritization regarding implementation of such technologies. Appropriate indicators need to be accessible and capable of summarizing the different and sometimes complex issues related to performance and impact. In this context, it is necessary to select a set of indicators for environmental, social and economic aspects of sustainability that are scientifically rigorous and are easy to communicate. The purpose of this deliverable is to review indicators that could be useful to judge technologies/innovations, which are going to be tested/applied to improve sustainability and close nutrient cycles in agricultural production systems. In this report, we will focus specifically on indicators that are relevant for Carbon (C), Nitrogen (N), and Phosphorus (P) cycles.

To organize information, the review process has been structured by indicator typologies and the causal chain between agricultural practices and their impacts. Although they can overlap in certain situations, we have divided indicator typologies into: i) agronomic indicators; ii) emission/resource consumption-based indicators; iii) environmental indicators; iv) economic indicators; v) social indicators; and finally vi) integrated sustainability indicators. Special emphasis has been put on prioritization of existing official schemes such as those from IPCC, European Commission and FAO.

For the environmental impact the impact categories of the Product Environmental Footprint (PEF) will be used, focussing on climate change, acidification, eutrophication and fossil resource depletion as most important categories for the Nutri2Cycle technologies as those are most relevant to CNP flows. The related environmental indicators are shown in Table ES1. These indicators will be used to conduct the preliminary qualitative assessment of technologies in Deliverable3.1.

Table ES1. 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	Nitrate (water emission)	Nitrate leached in the water from agricultural practices
	Phosphorus (water emission)	Phosphorus leached in the water from agricultural practices

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Impact category	Indicators	Aspect covered
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

To measure viability and profitability, the main economic indicator is the effect on the farmer's income. The income of a farmer depends on a number of other microeconomic indicators such as prices, costs, agricultural production and yields, market indicators (e.g. changes in human consumption) and subsidies (e.g. CAP pillar I and pillar II payments), which are influenced by macroeconomic indicators (e.g. GDP growth, exchange rates). The relevant microeconomic indicators will be used in the Cost-Benefit analysis of Deliverable 3.3, whereas the economic impact on overall production and trade will be analysed in WP4 on a regional scale.

Social indicators are still at preliminary stage of development with no consensual approach and lack of databases to assess some of the categories. However, the need to consider the different stakeholders such as workers, local communities, small-scale entrepreneurs and users, becomes evident. Being aware of the difficulties in the current proposals and the existing data gaps, one of the aims of the Nutri2Cycle is to contribute to include social indicators and provide assessments in agricultural projects, with special attention on consumer acceptance of new technologies. This work will be further elaborated in Deliverable 3.4.

From the review of the integrated sustainability indicators, we conclude that currently no widely accepted framework to derive an overall score on sustainability is available yet. The PEF initiative has suggested a list of normalisation and weighting factors, however, no agreement has been settled yet for the set of sustainability indicators. Instead, Multi-criteria decision analysis (MCDA) will be used in Nutri2Cycle for the evaluation and ranking of the solutions, which offers an approach to deal with potential conflicting criteria. MCDA will be used to synthetize the potential of the Nutri2Cycle technologies to effectively close nutrient loops, considering environmental costs, economic and social dimension and potential of implementation in the EU context.

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1. Introduction

Increasing evidence shows that food production is the largest cause of global environmental change, and a transition to sustainable food production is necessary for global sustainable development. During the last two decades, there has been an increasing demand for broader and integrative sustainability assessments, covering environmental but also the social and economic dimensions of sustainability. Although there is no universally agreed definition on what sustainability or sustainable development means, a broadly accepted definition is the one by the UN Brundtland Commission (Brundtland et al 1987):

"***Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs***".

Although this is very broad, it is the foundation for today's leading global framework for international cooperation on the UN 2030 Sustainable Development Goals (SDGs, 2015). In parallel, with the increasing awareness of sustainability concerns, we have seen the development of numerous models, tools and indicator-based methods, which are aimed at assessing the effects of agricultural activities in order to evaluate their sustainability. Scope, criteria and complexity of the different indicators vary depending on the aim and the frame for which they have been developed.

It is important to identify and provide easily understandable and scientifically based quantitative indicators that are accessible and capable of summarizing the different aspects and dimensions of sustainability in order to help decision-makers making prioritization of technologies and decisions about policy alternatives (Einarsson et al., 2018).

The Nutri2Cycle project aims to map current flows and gaps in C, N and P cycles in main agro-typologies (livestock production, crop production and agro-energy and residue processing) and develop and test a toolbox of comprehensible indicators to measure sustainability and evaluate trade-offs between the current practice and alternative, innovative technologies, and optimized farming systems for closing C, N and P loops. In this context, it is necessary to select a set of indicators of environmental, social and economic aspects of sustainability, which are scientifically rigorous and easy to apply and communicate.

According to the aim of the project, we have focused this review specifically on indicators that are relevant for carbon (C), nitrogen (N) and phosphorus (P) cycles, and ultimately to show the high potential of the proposed alternatives in closing C, N, P cycles. As a starting point of our review, we have checked for those relevant official schemes dealing with the definition of suitable indicators to assess sustainability.

Another relevant distinction is the scale of the assessment. Due to the nature of the Nutri2Cycle project, different scales shall be considered. Some indicators have been developed to make assessments at the field/farm scale, while others have been established to perform regional assessments. For the former, there is also a distinction between those systems that provide information on a farm-gate basis (e.g. Nutrient budget) and those that include the whole production

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chain (e.g. Nutrient footprint). At the first stage of implementation of indicators, it was agreed to use indicators at farm-gate scale, while in the scale up process (to a whole production chain) a broader scope of assessment could give more appropriate results. In addition, it is necessary to bear in mind that figures provided by indicators are often based on models, such as models to estimate emissions (e.g. kg NO_3^- leached) and models or algorithms to convert these emissions to indicators (e.g. eutrophication, kg N released).

To organize information, the review process has been classified according to indicators based on the causal chain between agricultural practices and their impacts. Although boundaries between them are sometimes difficult to establish, we maintain them according to definitions provided:

Farming system Indicators: Based mainly on agronomic information, soil status or productivity, fertilizer application and crop yields

Emission/commodity consumption-based Indicators: Expression of specific important emissions and consumption of important products like fertilizers or energy. .

Environmental Indicators: Expression of environmental impacts associated with environmental exchanges between the technosphere and the ecosphere

Economic indicators: Indicators based on economic profit and loss accounting, cost-benefit analysis etc.

Socio-economic indicators: Indicators mainly devoted to providing information on socio-economic aspects.

Sustainability Indicators: Integrative indicators that summarizes environmental, social and economic parameters.

Therefore, the goal of this deliverable/task is to perform a review of existing indicators to contribute to the process of selection and prioritization of technologies throughout the project (through WP1 and WP3 work using methods and models presented in D1.2). The indicators should support assessments at different stages in the project, both in situations where limited information is available and in situations when more comprehensive data is available. In addition, the indicators should provide measures of the performance of the innovative technologies and agricultural systems that are simple to understand and can be efficiently communicated.

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2. Indicator typology

2.1 Agronomic indicators

The trade-off between food production and environmental impacts is reflected in the duality of elements such as nitrogen (N), phosphorus (P) and carbon (C). They are essential for plant growth and soil fertility. However, when not well managed, these nutrients can provoke harmful effects on the environment (e.g. greenhouse gas or ammonia emissions), and inefficient nutrient use can result in an excess of nitrogen (N) and phosphorous (P). N and P excess can cause nitrate contamination in groundwater (N), high soil P levels and eutrophication of surface water (Galloway et al., 2018).

Different strategies have been used to quantify and to manage nutrients in soil at farm scale, for instance, based on nutrient budgets - one of the most simple and popular strategies for estimating indicators such as nutrients surplus (Watson et al., 2002). Nutrient Budgets (NB) or Nutrient surplus represent the nutrient balance, that is the difference between total nutrients imported into the farm (feed, fertilizers, etc.) and total amount of nutrient removed (fruits, milk, meat, etc.) from the farm, during a certain period. This difference is divided by the total farm area to be expressed as nutrient balance per ha (Galloway et al., 2018) (Equation 1).

$$NB_i = \frac{Imported_i - Exported_i}{Area\ t_i}$$

Equation 1. Calculation of Nutrient Budget or Nutrient surplus

Where:

NB = Nutrient Budget (nutrient balance/area) in period *i*.

Imported = Total nutrients imported into the farm (nutrient as input)

Exported = Total amount of nutrient removed from the farm (nutrient as output)

i = period over which the assessment is done

t_i = length of the assessment period i.

Nutrient balance could also be used to express a ratio, known as Nutrient Use Efficiency (NUE). The agro-environmental indicator NUE has various definitions in the literature and the calculation methods differ significantly. However, the principal idea is that NUE for each farm is calculated based on the nutrients exported in products as a percentage of the nutrients imported. For Nitrogen, this has been deliberated by the EU Nitrogen Expert Panel (2015), see Equation 2.

$$NUE = \frac{N\ outputs}{N\ inputs}$$

Equation 2. Calculation of Nitrogen Use Efficiency

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Where:

NUE = Nitrogen Use Efficiency

N outputs = Nitrogen emissions counted as an output from the system

N input = Nitrogen consumption counted as an input into the system

The N output (crop and animal products) per unit area is estimated from the total amount of products and the N content of the products exported from the farm in a production specific period. N output (kg N) = (Σ (mass of products (kg) x N concentration in products (kg N/kg product)) (EU Nitrogen Expert Panel, 2015).

Likewise, the N-input is calculated from the total amount of inputs and their N content in a specific period divided by the farmed area: N input (kg N) = (Σ (mass of input (kg) x N concentration in input (kg N/kg input))/ (EU Nitrogen Expert Panel, 2015).

Furthermore, the N output content in products (as an indicator of productivity) and the N surplus (N input – N output) in products, as a proxy indicator for potential N losses) was proposed as an integrated part of this version of the NUE indicator. For a detailed description of NUE, we address the reader to the document EU Nitrogen Expert Panel (2015).

Another popular agricultural indicator is the Soil Organic Carbon (SOC) content. SOC can be used as an indicator of soil fertility, soil degradation and the effect of technologies on SOC can be used to guide agricultural policies Improvement of SOC stock or soil C sequestration has been included as one of the issues related to agriculture to combat climate change (COP23, 2017). Although both organic and inorganic forms of C are found in soils, land use and management typically have a larger impact on organic C stocks. Consequently, the methods usually provided focus mostly on soil organic C. The influence of land use and management on soil organic C is different depending on the soil type and initial SOC content. Using soil classification and mapping allow for the development of SOC change assessment for the different land uses. However, usually SOC stock changes are very small relative to the total stock, and hence actual measurement of SOC changes from field soil sampling and chemical analysis is challenging, due to inherent soil spatial variability, sampling and analytical random errors. This means that actual measurement of SOC change over short time intervals (<10 years) is usually not reliable; decadal time-scales are needed for such measured SOC changes to be significant. For this reason, various models have been developed to estimate the soil organic carbon change in time and the relation with nitrogen or water cycle allows for crop yield predictions.

It is clear that because of the relatively ease with which agronomic information can be collected, agronomic indicators such as NUE and input of effective organic matter, SOMs as indicator of potential SOC changes could be a relatively simple and useful starting point for an indicator set.

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2.2 Emission/ commodity consumption-based indicators

In the frame of planetary boundaries definition (Rockström et al 2009), those in relation to biogeochemical flows: interference with P and N cycles have shown some of the most critical. Production, application, and trade of mineral fertilisers has contributed to disrupt global nitrogen and phosphorus cycles. Excessive application of nitrogen and phosphorus has substantial consequences, resulting from losses to the atmosphere, streams and rivers, driving eutrophication of terrestrial, freshwater and marine ecosystems (Willet et al. 2019). Therefore, with the growing awareness on environmental problems, numerous agri-environmental indicators and indicator-based methods have been developed to assess the adverse effects of cropping and farming systems such as gaseous emissions due to nitrogen inputs, water pollution by nitrates and pesticides, etc. In parallel, reviews and comparative studies of these indicators have been performed (e.g. Bockstaller et al., 2008; Einarsson et al., 2018; Galan et al., 2007; Halberg et al., 2005; Hoang and Alauddin, 2010; Kanter et al., 2018; Langeveld et al., 2007; Payraudeau and van der Werf, 2005; van der Werf and Petit, 2002).

For most of the nutrient flows that need to be quantified in feed supply chains, existing guidelines have defined relevant methods. The Livestock Environmental Assessment and Performance Partnership, LEAP, Feeds Guidelines (FAO, 2016) cover all aspects of feed production and material flows associated with production of a wide range of crop and pasture systems through to the animal's mouth. In addition, LEAP, provide also guidelines to introduce a harmonized international approach assessing nutrient flows and impact assessment for eutrophication and acidification (FAO, 2018) and measuring and modelling soil carbon stocks and stock changes from grasslands and rangelands (FAO 2019) for livestock supply chains.

The initiative of FAO (SAFA 2014), *Sustainability Assessment of Food and Agriculture Systems*, SAFA, provide guidelines to assess sustainability of farms. This includes several indicators in relation to nutrient flows and greenhouse emissions. These authors, being aware of the lack of specific metrics to rely on, suggest the use practice-based indicators as a proxy for performance. They addressed the environmental items of Atmosphere, Water, Land, Materials and Energy, Biodiversity and Animal Welfare developing a series of indicators. In relation to Nutri2Cycle goals, we underline greenhouse gases, air pollution, soil quality, material and energy use (special focus on renewable ones) and waste management (reduction and recovery)

In 2017, the European Commission developed a reference indicator framework to monitor the SDGs in an EU context. The EU SDG indicator set serves as the basis for Eurostat's annual monitoring report on progress towards the SDGs in an EU context (EU SDG, 2020). Eight of the indicators are closely linked to nutrient flows, covering: i) ammonia emissions (SDGI 2.60); ii) nitrate in groundwater (SDGI 6.40); iii) phosphate in rivers (SDGI 6.50); iv) exposure to air pollution by particulate matter (SDGI 11.50); v) share of renewable energy in gross final energy consumption (SDGI 7.40); vi) circular material use rate (SDGI 12.41): vii) greenhouse gas emissions (SDGI 13.10); viii) Greenhouse gas emissions intensity of energy consumption (SDGI 13.20).

The implementation of the Common Agricultural Policy, CAP, 2014-2020 has been measured against a set of indicators that covers all policy areas and provides information at various levels. A set of 28

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Agri-environmental indicators (AEIs) was developed by the Commission to track the integration of environmental concerns into CAP at EU, national and regional levels. Because of the European frame of Nutri2Cycle project and the importance to have reference or benchmarked values to compare potential novel technologies, we highlight the importance of using the Agri-environmental indicators (EU-AI, 2020) or Common Context Indicators for Rural Development programs of European Commission (EU-CCI, 2020), which report information on the existing farmed environmental indicators. Building on these initiatives table 1 provides a summary of main emissions and consumption of commodities involved in the C, N, P cycles suggesting the corresponding indicators, units, and reference indicator from relevant EU initiatives. Units of indicators provided at table 1 are referred to hectare as a unit of analysis, this could be changed (e.g. yield, farm, animal) depending on the goal of the assessment.

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Table 1. Main flow emissions and resources (inputs/outputs) linked to corresponding agricultural or livestock activities. Institution, which provides guidelines for assessment and reference indicators according to AEI, Agri-environmental Indicator (EU-AI, 2020), and CCI, Common Context Indicators for Rural Development programs (EU-CCI, 2020)

emission/resource	Units indicators	Activity involved	Guidelines provided by	Reference EU-AI 2020	Reference EU-CCI 2020[14]
N consumption	Kg N / ha	Fertilizers application	EU-AI 2020	AEI5[3]	
P consumption	Kg P/ ha	Fertilizers application	EU-AI2020	AEI5[3]	
Water consumption	m^3 / ha	Agriculture, livestock, waste management	EU-AI2020	AEI7[4]	CCI39[15]
Energy use	MJ equivalent / ha	Agriculture, livestock, waste management	OECD/IEA 2004	AEI8[5]	CCI44[16]
Renewable energy production	MJ equivalent / ha	Agriculture, livestock, waste management	OECD/IEA 2004	AEI24[6]	CCI43[17]
Soil organic matter	ton / ha	Agriculture and fertilizer practices, Livestock	FAO 2019		CCI41[18]
Ammonia NH_3 (air emission)	ton N-NH_3 / ha	Animal at farm Manure management Organic and mineral fertilizers application	EEA 2019	AEI19[7]	CCI45[19]
GHG emissions, CO_2, CH_4, N_2O	ton CO_2 equivalent/ha = ton CO_2*1 ton CO_2 eq/ ton CO_2 + ton CH_4 *34[1] ton CO_2 eq/ ton CH_4 + ton N_2O *298 ton CO_2 eq/ ton N_2O	Emissions from enteric fermentation Manure management Rice cultivation Organic and mineral fertilizer application	IPCC 2019	AEI18[8]	CCI45[19]
Particulate matter	mg $PM_{2.5}$ and PM_{10}/ha	Organic and mineral fertilizers application Labour operations Animal at farm	EEA 2019		
Nitrate pollution	agricultural emissions of nitrogen to freshwater (kg N-NO_3/ha)	Fertilizers and field management, Livestock	IPCC 2019, FAO 2018	AEI15[9] AEI27.1[10]	CCI40[20]

[1] The Fifth assessment report of IPCC (2013) reports a global warming potential for methane at 34 (including climate-carbon feedbacks), still with the exclusion of methane oxidation into carbon dioxide and which is valid for biogenic methane only (IPCC 2013, Table 8.7). IPCC (2013) refers to Boucher et al. (2009) calculated an upper limit of +2.5 when considering that all methane is converted into CO_2 and up to +2.75 with a longer time horizon, being 36,75 the recommended global warming potential factor to be used for fossil methane by PEFCR (2018).

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Phosphorus pollution	agricultural emissions of phosphorus to freshwater (kg P/ha)	Fertilizers and field management, Livestock	EU-AI 2020, FAO 2018	AEI16[11]	CCI40[20]
Soil quality	Agri-environmental soil quality index[2] Soil environmental services, Soil Organic carbon	Soil erosion and agricultural practices, Livestock	EU-AI 2020, JRC, Revised Universal Soil Loss Equation (RUSLE), FAO 2019	AEI21[12] AEI26[13]	CCI42[21]

[2] Soil Quality Index: Several indicators could be included, see Fazzio et al (2018) because of its robustness we would suggest focus on erosion

[3] AEI 5: Mineral fertiliser consumption (https://ec.europa.eu/eurostat/statistics-explained/index.php/Agri-environmental_indicator_-_mineral_fertiliser_consumption)

[4] AEI 7: Irrigation (https://ec.europa.eu/eurostat/statistics-explained/index.php/Agri-environmental_indicator_-_irrigation)

[5] AEI 8: Energy use (https://ec.europa.eu/eurostat/statistics-explained/index.php/Agri-environmental_indicator_-_energy_use)

[6] AEI 24: Production of renewable energy (https://ec.europa.eu/info/sites/info/files/food-farming-fisheries/farming/documents/cap-indicators-doc-c43_2018_en.pdf)

[7] AEI 19: Greenhouse gas emissions (https://ec.europa.eu/eurostat/statistics-explained/index.php/Climate_change_-_driving_forces#Agricultural_emissions)

[8] AEI 18: Ammonia emissions (https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Archive:Agri-environmental_indicator_-_ammonia_emissions)

[9] AEI 15: Gross Nitrogen Balance (https://ec.europa.eu/eurostat/statistics-explained/index.php/Agri-environmental_indicator_-_gross_nitrogen_balance)

[10] AEI 27.1: Water Quality - Nitrate pollution (https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Archive:Agri-environmental_indicator_-_nitrate_pollution_of_water)

[11] AEI 16: Risk of pollution by phosphorus (https://ec.europa.eu/eurostat/statistics-explained/index.php/Agri-environmental_indicator_-_risk_of_pollution_by_phosphorus)

[12] AEI 21: Soil erosion (https://ec.europa.eu/eurostat/statistics-explained/index.php/Agri-environmental_indicator_-_soil_erosion)

[13] AEI 26: Soil quality (https://ec.europa.eu/eurostat/statistics-explained/index.php/Archive:Agri-environmental_indicator_-_soil_quality)

[14] https://ec.europa.eu/info/sites/info/files/food-farming-fisheries/farming/documents/cap-context-indicators-table_2019_en.pdf

[15] CCI 39: Water abstraction in agriculture

[16] CCI 44: Energy use in agriculture, forestry and food industry

[17] CCI 43: Production of renewable energy from agriculture and forestry

[18] CCI 41: Soil organic matter in arable land

[19] CCI 45: Emissions from agriculture

[20] CCI 40: Water quality

[21] CCI 42: Soil erosion by water

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2.3 Environmental indicators

Environmental indicators used in the current deliverable will take Life Cycle Impact Assessment (LCIA) methodology as a point of departure. Life Cycle Impact Assessment is a standardized method of calculating possible environmental impacts from products, services and processes, and LCIA is the phase where impacts associated with emissions and resource consumptions are characterized. In LCIA, the impacts are divided into impact categories, according to effects on the environment. For instance, C, N and P cycles (and respective emissions) will impact directly on:

i. Eutrophication: mainly through NO_3^- and PO_4^{2-} emissions
ii. Acidification: mainly through NH_3 emissions
iii. Climate change: mainly through C sequestration and CH_4 and N_2O emissions
iv. Resources depletion: because of fossil energy consumption and replacement through renewables production (i.e. biogas, biomass) and raw materials (i.e. Phosphate rock)
v. Respiratory organics: through ultrafine Particulate Matter (PM) released, NH_3 emissions contribute

It is important to be aware that depending on the technology, other emissions and resource consumptions may results in other environmental impacts, such as, toxicity, water scarcity, etc.

In LCIA, impact models are used to calculate characterization factors or impact factors that can be used to convert elementary flows (emissions and resource consumptions) to environmental impacts in different categories. Because of the proliferation of different impact models, several initiatives seek to strengthen and harmonize methods to be applied. Among these initiatives, we would highlight those conducted by the FAO-Livestock Environmental Assessment and Performance (LEAP 2020), UNEP-SETAC Life Cycle Initiative (UNEP 2018) and the European Platform for Life Cycle Assessment (EPLCA 2020).

Due to the EU scope of the Nutri2Cycle project, we will follow recommendations in relation to impact assessment models to be applied of the Environmental Footprint (EF) (EU 2018), which is derived from the International Life Cycle Data system, ILCD scheme (EU-JRC, 2011).

Table 2 presents the recommended methods and highlights the most relevant impact categories in relation to the N, C and P cycles: climate change, eutrophication, acidification, resource depletion (fossil and mineral). Table 2 also includes level of robustness for each impact category, which give an idea of certainty of method. Robustness corresponds to the recommendation level of EF ranging from level I for models and characterisation factors which are recommended for all types of life cycle-based decision support, to level III recommended, but only with caution given the considerable uncertainty, incompleteness or other shortcomings, aspects that need to be considered when LCA will be performed.

Table 3 lists characterization factors, i.e. factors that establish the relation between the elementary flows (emissions or resources) and the environmental impacts, according to the recommended Environmental Footprint method EF3.0. The reader is advised to consult the corresponding reference (Fazio et al., 2018) for more details on this subject.

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Table 2. Recommended Impact categories, indicator, units default Impact assessment model and level of robustness (Level I =recommended and satisfactory, Level II = recommended but in need of some improvements, and Level III = recommended, but to be applied with caution), based on Fazio et al. (2018)

Impact category	Indicator	Unit	Recommended default impact model	Robustness
Climate change	Radiative forcing as Global Warming Potential (GWP100)	kg CO_2 eq	Baseline model of 100 years of the IPCC (based on IPCC, 2013)	I
Ozone depletion	Ozone Depletion Potential (ODP)	kg CFC-11eq	Steady-state ODPs as in (WMO, 1999)	I
Human toxicity, cancer effects*	Comparative Toxic Unit for humans (CTUh)	CTUh	USEtox model (Rosenbaum et al., 2008)	III/interim
Human toxicity, non-cancer effects*	Comparative Toxic Unit for humans (CTUh)	CTUh	USEtox model (Rosenbaum et al., 2008)	III/interim
Particulate matter/Respiratory inorganics	Human health effects associated with exposure to PM2.5	Disease incidences	PM model recommended by UNEP (UNEP, 2016)	I
Ionising radiation, human health	Human exposure efficiency relative to U235	kBq U235	Human health effect model as developed by Dreicer et al., 1995 (Frischknecht et al., 2000)	II
Photochemical ozone formation	Tropospheric ozone concentration increase	kg NMVOC eq	LOTOS-EUROS (Van Zelm et al., 2008) as applied in ReCiPe 2008	II
Acidification	Accumulated Exceedance (AE)	mol H+ eq	Accumulated Exceedance (Seppälä et al. 2006, Posch et al., 2008)	II
Eutrophication, terrestrial	Accumulated Exceedance (AE)	mol N eq	Accumulated Exceedance (Seppälä et al., 2006, Posch et al., 2008)	II
Eutrophication, aquatic freshwater	Fraction of nutrients reaching freshwater end compartment (P)	kg P eq	EUTREND model (Struijs et al., 2009) as implemented in ReCiPe	II
Eutrophication, aquatic marine	Fraction of nutrients reaching marine end compartment (N)	kg N eq	EUTREND model (Struijs et al., 2009) as implemented in ReCiPe	II
Ecotoxicity (freshwater)*	Comparative Toxic Unit for ecosystems (CTUe)	CTUe	USEtox model, (Rosenbaum et al., 2008)	III/interim
Land use	Soil quality index (Biotic production, Erosion resistance, Mechanical filtration and Groundwater replenishment	Dimensionless, aggregated index of: (kg biotic production, kg soi,ll m^3 water,m^3 g.water)/ (m^2*a)	Soil quality index based on LANCA (Beck et al., 2010 and Bos et al., 2016)	III
Water scarcity	User deprivation potential (deprivation-weighted water consumption)	kg world eq. deprived	Available WAter REmaining (AWARE) in UNEP, 2016	III
Resource use, minerals and metals	Abiotic resource depletion (ADP ultimate reserves)	kg Sb eq	CML Guinée et al. (2002) and van Oers et al. (2002).	III
Resource use, energy carriers	Abiotic resource depletion – fossil fuels (ADP-fossil)	MJ	CML Guinée et al. (2002) and van Oers et al. (2002)	III

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Table 3. Characterization factors for selected environmental flows and their corresponding impact category according to EF 3.0 (Fazio et al., 2018)

Substance	Unit	Climate change	EF-particulate Matter	Acidification terrestrial and freshwater	Eutrophication freshwater	Eutrophication marine	Eutrophication terrestrial	Resource use, minerals and metals	Resource use, energy carriers
		kg CO_2 eq	disease inc.	mol H^+ eq	kg P eq	kg N eq	mol N eq	Kg Sb	MJ
Resources									
CO_2 sequestration	kg	-1	NA	NA	NA	NA	NA	NA	NA
crude oil	MJ	NA	NA	NA	NA	NA	NA	NA	1
natural gas	MJ	NA	NA	NA	NA	NA	NA	NA	1
phosphorus	kg	NA	NA	NA	NA	NA	NA	5.52E-06	NA
Emissions to air									
Ammonia	kg	NA	2.10E-05	3.02	NA	0.092	13.47	NA	NA
Carbon dioxide	kg	1	NA	NA	NA	NA	NA	NA	NA
Dinitrogen monoxide	kg	298	NA	NA	NA	NA	NA	NA	NA
Methane, fossil	kg	36.8	NA	NA	NA	NA	NA	NA	NA
Methane, biogenic	kg	34	NA	NA	NA	NA	NA	NA	NA
Nitrogen oxides	kg	NA	2.10E-07	NA	NA	0.39	NA	NA	NA
Particulates, < 2.5 um	kg	NA	2.38E-04	NA	NA	NA	NA	NA	NA
Particulates, > 2.5 um, and < 10um	kg	NA	5.49E-05	NA	NA	NA	NA	NA	NA
Emissions to water									
Nitrate	kg	NA	NA	NA	NA	2.80E-02	NA	NA	NA
Phosphorus	kg	NA	NA	NA	1	NA	NA	NA	NA

NA = The substance is not related (not impacting) to the impact category

Based on the current review for agronomic, emissions, commodity consumption and environmental indicators, we suggest working with the most relevant ones for nutrients recovery, those showing straight relationship and the highest robustness level according to table 2 and comparing them against references or baseline scenarios. Table 4 shows the suggested selection of indicators to be included and to be applied in Nutri2Cycle Deliverable 3.1 to screen the different technologies to be tested. This screening will be conducted first as a qualitative assessment, but for further semiquantitative assessment, we provide guidelines on indicators to be used for indicators accounting and corresponding source.

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Table 4. List of proposed indicators, dimension, aspects covered, guidelines to account for and corresponding source

Dimension	Indicators	Aspect covered	Guideline	Source
Use of primary resources	Phosphate ore	Rock phosphate used to produce P fertilizers	To produce 1 kg Phosphate rock, with 32% P_2O_5, requires 5 kg Phosphate ore.	AGRIBALYSE v 3.0 (Colomb et al 2014)
	Natural gas	Natural gas avoided by nutrients recovery	813 L Natural Gas / 1kg Nitrogen fertilizer as N 273 L natural gas /1 kg Phosphate Fertilizer as P_2O_5	Ecoinvent 3.0.3.1 (Werner et al 2016)
	Oil	Crude oil used to produce P fertilizers	463 g crude oil /1kg Nitrogen fertilizer as N 106 g crude oil/1 kg Phosphate Fertilizer as P_2O_5	Ecoinvent 3.0.3.1 (Wernet et al 2016) Ecoinvent 3.0.3.1 (Wernet et al 2016)
	Energy	Energy consumption in agriculture	Data expressed in tonnes of oil equivalents.	Eurostat (2005)
	Water	Water consumption	Water abstraction in agriculture	Cropwat (FAO 1998)
	Soil quality	Soil quality index (Biotic production, Erosion resistance, Mechanical filtration and Groundwater replenishment)	LANCA Soil quality index	Fazio et al (2018)
	Nutrients recovered	N and P recovered from agricultural practices	Table A. Composition of organic fertilisers	Avadi et al. (2020)
Emissions to environment	Ammonia (air emission)	Ammonia emitted to the air from agricultural practices	NFR 3.B Manure Management NFR 3 D Crop production and agricultural soils	Ntziachristos, L., & Samaras, Z. (2019)
	Dinitrogen monoxide (air emission)	Dinitrogen monoxide emitted to the air from agricultural practices	Soil Management Manure Management	IPCC 2019 chapter 11 section 11.2 IPCC 2019 chapter 10 section 10.5
	Methane (air emission)	Methane emitted to the air from agricultural practices	Enteric Fermentation Manure Management	IPCC 2019 chapter 10 section 10.3 IPCC 2019 chapter 10 section 10.4
	Nitrates (water emission)	Nitrate leached in the water from agricultural practices	0.44 kg NO_3^- water emission/ kg N applied	PEFCR (2018)
	Phosphorus (water emission)	Phosphorus leached in the water from agricultural practices	Through leaching to ground water Through run-off to surface water Through water erosion to surface water	Prasuhn, V. (2006)
	Particulate matter	PM_{10} emitted to the air from agricultural practices	NFR 3.B Manure Management NFR 3 D Crop production and agricultural soils	Ntziachristos, L., & Samaras, Z. (2019)
Climate change	Carbon footprint	Greenhouse gases Land use changes	See Table 3 Characterization factors for corresponding environmental flows according to EF 3.0	Fazio et al 2018 + IPCC 2019
	Soil organic matter	Addition of effective organic matter to soil	Soil organic carbon stock changes	FAO (2020) GSOC MRV Protocol
	Renewable energy	Renewable energy produced	No indicators available	
Productivity	Crop Yield	Crop yield improved/decreased		
	Livestock production	Livestock production improved/decreased		

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2.4 Economic indicators

To evaluate the economic performance of the proposed mitigation technologies the relevant economic indicators influencing farmers decision to implement these technologies have to be identified. In general, the economic responsiveness in the agricultural sector to a specific shock such as the implementation of a new technology is usually expressed in terms of elasticities. However, since most of the proposed mitigation technologies are innovative and have a low TRL level, no sufficient statistical data is currently available for estimating the respective elasticities. Therefore, the economic responsiveness of applying a certain mitigation technology will be assessed in terms of the increase in implementation share of the technology if a subsidy is granted. The currently implemented approach to estimate these abatement cost curves is elaborated in Pérez Domínguez et al. (2020). Thus, with a certain subsidy level the implementation share of the technology will reach its technical limit. Regarding the uptake of the proposed technologies two cases are considered. First, for the technologies that are already implemented in the base year it is assumed that the maximum implementation share (given in the GAINS database) will be reached if a relative subsidy of 80 % of the accounting costs is granted. Second, for the technology option that are new and that have zero implementation share in the base year it is assumed that a relative subsidy of 20% of the accounting costs is needed to attract the first adopter. To reach the maximum implementation share a relative subsidy of 120 % is necessary.

After specifying the economic responsiveness mechanism of the proposed technologies, we can identify the main economic indicators represented in this modelling framework affecting the profitability and hence the implementation shares of different technologies in the member states of the European Union. Combined with information on yields and production, a range of indicators depending on the output (i.e. farm, total production, unit of production, etc.) is relevant and compiled to measure the profitability of the farm, in its several dimensions.

In Table 5 the main micro- and macroeconomic indicators related to the proposed technological advancements are presented. The microeconomic indicators have a more detailed representation as the impact of the proposed technologies on the macroeconomic environment is expected to be non-significant. As the main objective of the farmer is to maximize the income the decision of whether to adopt a technology or not will be closely linked to this economic indicator. The income of a farmer itself depends on a number of other economic indicators: prices, costs, agricultural production and yields, different market indicators and subsidies. These aggregate microeconomic indicators are in their turn influenced by the macroeconomic indicators and vice versa (Table 5).

The price-related economic indicators consist of different price categories: market price of the produced output; producer price which is the price received by the producer and the difference between the producer price and market price are the production related direct and indirect subsidies; consumer price is the price paid by the consumers; and import/export prices.

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When adopting a technology farmer will be faced with two types of investment costs: fixed and farm size dependent. Moreover, farmer has also to bear operating and maintenance costs as well as the costs associated with the intermediate inputs. Agricultural area and yield indicators also have a direct impact on farm income as they will be directly impacted by the adopted mitigation technologies.

Market indicators represent the demand-side of the market and will have a direct influence on the production decisions of the farmer. The CAP pillar I and pillar II payments such as ecological focus area %, budgetary national envelope, voluntary coupled payments, young farmers payments, greening payments and price support are an important source for farm income.

The implementation of the proposed technologies might also affect the labour requirements for specific agricultural activities. The results on farm income can be aggregated to obtain the cost and revenues of the farm sector which allows analysing the overall impacts on production and trade on a regional, national and European level (Britz and Witzke, 2015).

Table 5: Economic indicators for different farm activities

	Description	Unit
Microeconomic indicators	**Prices and income**	
	Real producer price/input price	Euro/t
	Market price	Euro/t
	Consumer price	Euro/t
	Import/export price	Euro/t
	Regional agricultural income (Revenues - Total costs + premiums)	Euro per ha or head
	Costs	
	Fixed investment costs	Euro
	Farm size dependent investment costs	Euro/ha
	Operating costs (e.g fuel, electricity)	Euro/ha
	Maintenance costs per year	Euro
	Intermediate inputs (e.g. fertiliser costs, feed costs)	Euro
	Other costs	Euro
	Agricultural area and yield	
	Area harvested/number of animals	ha/heads
	Land cover (including grassland, arable land, wetlands, forest etc.)	ha
	Crop yield	dm t/ha, fm t/ha
	Market indicators	
	Human consumption	t
	Feed use	t
	Seed use	t
	Processing to secondaries	t
	Biofuels processing	t
	Other industrial production	t
	Losses on market	t

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	Description	Unit
	Production	t
	Imports	t
	Exports	t
	Net trade	t
	Self-sufficiency rate (production/domestic use)	Ratio
	CAP pillar I payments	
	Voluntary Coupled Support (VCS) payments	Euro
	Greening payments	Euro
	Young Farmer Payments	Euro
	Redistributive Payment	Euro
	Basic farm payment	Euro
	BPS Single Area payment	Euro
	CAP pillar II payments	
	Less favoured area payments	Euro
	Natura 2000 payments	Euro
	Agri-environmental payments	Euro
Macroeconomic indicators	Inflation	%
	Exchange rate	Ratio
	GDP growth	%
	World prices	Euro
	Factor productivity changes	%
	Unemployment rate	%
	Government deficit/surplus	Euro
	Government debt	Euro
	Gross Value Added	Euro
	Population growth	%

In addition, the implementation share of technologies and management systems also depends on the macroeconomic environment and the agricultural market development of a particular country or region. Macroeconomic indicators cover, for example, GDP growth, inflation, exchange rates, world price developments, labour productivity, employment and population growth, international trade, government deficit/surplus, debt, gross value added (Fellmann et al., 2016).

In the Nutri2Cycle project also policy measures and their potential influence on the uptake of innovations and improving the efficiency of nutrient and carbon cycles are analysed. A key element to analyse policy changes from an economic viewpoint is to look at welfare changes such as changes in consumer and producer rents and for the tax payer.

Changes in consumer rents can be indicated by changes in the purchasing power of consumers as suggested in the money metric concept. On the producer side main indicators can be changes in the gross value added (GVA) plus premiums. The gross value added is the difference between revenues (output quantities valued at farm gate prices) and intermediate input costs (input quantities with the

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exemption of the primary factors land, capital and labour multiplied with their farm gate prices). The GVA plus premiums is hence the sum the farming sector can spend to enumerate labour, capital and land, independent on property rights of these factors. The main indicators for taxpayer costs can refer to those policy instruments explicitly covered, i.e. premiums paid to farmers, cost of public market interventions and export subsidization and some subsidies paid for demanders of agricultural goods, minus revenues from import tariffs (Britz and Witzke, 2015).

Additionally, land use changes due to the implementation of the proposed technologies and analysed policy scenarios will also be taken into consideration. This is an important aspect in terms of land use change related GHG emissions, nutrient related pressures and biodiversity enabling us to account for potential leakage and rebound effects.

Since the economic assessment of the proposed technologies will be conducted in a partial equilibrium framework some interconnections with other (non-agricultural) markets will not be considered, e.g. labour and capital markets, financial markets, etc. The justification of the choice of the modelling framework is that the assumed impact of the technologies on the non-agricultural markets is assumed to be not significant.

2.5 Social indicators

Until very recently, most of the studies focus on environmental impacts of agricultural systems, without considering social components (Darnhofer et al., 2010), leading to an imbalance between the three dimensions of sustainability. However, the need to have information on the consequential economic and social costs of current activities and their technological more environment-friendly alternatives has become evident. We will use the life cycle perspective to address the potential shifting of consequences along the whole production chain or among sustainability aspects and dimensions.

Social life cycle assessment (S-LCA) is a methodology that aims to assess socioeconomic impacts of products considering their life cycles and stakeholders involved. The 2009 publication of the UNEP/SETAC “Guidelines for Social Life Cycle Assessment of Products” represent an important first step towards developing consensus methodologies for s-LCA (Benoît and Mazijn, 2009). A list of 31 subcategories (or criteria) has been developed (table 6) based on a consultation process with a wide range of stakeholders (worker and employer trade unions, consumer and private sector associations, NGOs, UN bodies). Subcategories are classified according to five types of stakeholder that can be affected by the practices of companies, namely, workers, consumers, value chain actors, local community, society, and can be classified according to the six impact categories proposed by the Guidelines (human rights, working conditions, governance, cultural heritage, health and safety, and socioeconomic repercussions). However, the Guidelines do not specify links between subcategories and impact categories. As a follow-up, “The Methodological Sheets for Subcategories in Social Life Cycle Assessment” (Benoît et al., 2013) discusses the link between each subcategory and sustainable development and proposes corresponding indicators and sources.

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One approach to conduct a comprehensive S-LCA analysis is through the use of a quantitative social database, ideally followed by a case-specific analysis to verify generic data results (Werker et al., 2019). Therefore, the development of databases certainly facilitates performance S-LCA, especially those which intend to identify hotspots (Benoît and Mazijn, 2009). Thus, an approach that could be used in the Nutri2Cycle project is using a social database, in this case, the Product Social Impact Life Cycle Assessment (PSILCA) database.

PSILCA is a consistent and transparent social database that can be used to assess social impact along product life cycles. This database assesses the impacts as risks and opportunities through the value chain of different products and processes (not specifically related to agriculture, but including this sector) using 74 generic indicators divided in nine impact categories, encompassing four out five stakeholders considered in S-LCA, 'workers', 'local community', 'value chain actors' and 'society' (Table 7). Therefore, in the present study, a quantitative analysis through PSILCA database is the main method to assess social impacts in pig production to create a baseline scenario for the European countries involved in the Project Nutri2Cycle.

Table 6. Social impact categories used in S-LCA and highlighted (in bold) relevant impact categories for the technologies/solutions in the Nutri2Cycle project

	Stakeholder	Categories
S-LCA	Workers	Freedom of Association and Collective Bargaining Child Labour **Fair Salary** **Hours of Work** Forced Labour Equal Opportunities / Discrimination **Health and Safety** **Social Benefit / Social Security**
	Consumers	Health and Safety Privacy Transparency End-of-Life Responsibility
	Value Chain Actors	Fair Competition Respect of Intellectual Property Rights **Supplier Relationships** Promoting Social Responsibility
	Local Community	Delocalization and Migration Community Engagement Cultural Heritage Respect of Indigenous Rights **Local Employment** **Access to Immaterial Resources** **Access to Material Resources** **Safe and Healthy Living Conditions** **Secure Living Conditions**
	Society	Public Commitment to Sustainability Issues

	Stakeholder	Categories
		Prevention and Mitigation of Conflicts **Contribution to Economic Development** **Corruption** **Technology Development**

Table 7. Impact subcategories and social indicators in PSILCA database and highlighted (in bold) relevant impact categories for the technologies/solutions in the Nutri2Cycle project

Stakeholder	Subcategory	Indicators
Local Community	GHG Footprints	Embodied CO_2 footprint
		Embodied CO_2-eq footprint
	Environmental Footprints	Embodied agricultural area footprint
		Number of threatened species
		Embodied forest area footprint
		Embodied water footprint
	Access to material resources	Certified environmental management systems
		Extraction of biomass (related to population)
		Extraction of biomass (related to area)
		Extraction of fossil fuels
		Extraction of industrial and construction minerals
		Extraction of ores
		Level of industrial water use (related to total withdrawal)
		Level of industrial water use (related to renewable water resources)
	Respect of indigenous rights	Indigenous People Rights Protection Index
		Presence of indigenous population
	Migration	International Migrant Stock
		International migrant workers in the sector
		Human rights issues faced by migrants
		Immigration rate
		Emigration rate
		Net migration rate
		Number of asylum seekers in relation to total population
	Labor footprints	Embodied value added total
	Safe and healthy living conditions	**Pollution level of the country**
		Drinking water coverage
		Sanitation coverage
	Local employment	**Unemployment rate in the country**
Value Chain Actors	Corruption	Active involvement of enterprises in corruption and bribery
		Public Sector Corruption
	Fair Competition	Presence of anti-competitive behaviour or violation of anti-trust and monopoly legislation
	Risk of conflicts	Global Peace Index

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Stakeholder	Subcategory	Indicators
	Promoting social responsibility	Membership in an initiative that promotes social responsibility along the supply chain
Workers	Child labour	Children in employment, female
		Children in employment, male
		Children in employment, total
	Discrimination	Gender wage gap
		Men in the sectoral labour force
		Women in the sectoral labour force
	Fair salary	**Living wage Lower bound**
		Living wage Upper Bound
		Living wage, per month (AV)
		Minimum wage, per month
		Sector average wage, per month
	Forced labour	Frequency of forced labour
		Goods produced by forced labour
		Trafficking in persons
	Freedom of association and collective bargaining	Right of Association
		Right of Collective bargaining
		Right to Strike
		Trade union density
	Healthy and Safety	**DALYs due to indoor and outdoor air and water pollution**
		Presence of sufficient safety measures
		Rate of fatal accidents at workplace
		Rate of non-fatal accidents at workplace
		Violations of mandatory health and safety standards
		Workers affected by natural disasters
	Social benefits, legal issues	Evidence of violations of laws and employment regulations
		Social security expenditures
	Working time	**Weekly hours of work per employee**
Society	Contribution to economic development	Illiteracy rate, female
		Illiteracy rate, male
		Illiteracy rate, total
		Public expenditure on education
		Youth illiteracy rate, female
		Youth illiteracy rate, male
		Youth illiteracy rate, total
	Healthy and Safety	Domestic and external health expenditure (% of current health expenditure)
		Domestic general government health expenditure (% of current health expenditure)
		Health expenditure, external resources
		Health expenditure, out-of-pocket

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Stakeholder	Subcategory	Indicators
		Health expenditure, public
		Health expenditure, total
		Life expectancy at birth

The benefits (positive impact) promoted by the novel technologies will be assessed through a qualitative analysis (quantitative when possible) and adopting a prospective approach using several indicators divided by stakeholders, such as new job positions, training courses for workers, new source of damage to farm workers, reduced odour in the farm, better water quality, new knowledge and scientific purpose, improvement on animal life conditions. A review of social indicators that can be used to assess novel technologies will be provided.

It is important to highlight that there is no standardized methodology in S-LCA, therefore, more indicators can be aggregated on the social assessments, conducting the study to the intended goals. Therefore, for the social assessments in Nutri2Cycle, besides social impacts considered in S-LCA, other indicators will be included according to the need to complement the assessments, for instance, “Training and employee development”, “High-level skills from workers”, “New knowledge and scientific purpose” that are more related to the inclusion of new technologies for nutrient recovery in agriculture. Again, although there is a Guideline for S-LCA, the indicators are suggested, therefore, there is more freedom when selecting those for the assessments, and they can vary (regarding relevance) between the technologies, according to their main purpose. In the following deliverables, the social indicators will be more explored.

The impacts for the ‘consumers’ of agricultural products, which are not included in PSILCA, will be assessed in the WP5 of Nutri2Cycle, and will not be dealt with here.

2.6 Integrated sustainability indicators

Several proposals have been suggested to deal with a more or less simplified version of sustainability indicators. Most of them are based on some kind of qualitative indicator, and they are developed at different scales from farm to regional ones.

In the frame of the Circular Economy, we could highlight the “Circularity Indicators Project” (MacArthur et al. 2015). This project focusses on quantifying the restoration of material flows and the development of a Material Circularity Indicator (MCI). Other considerations (e.g. toxicity, scarcity and energy) are included as complementary indicators. The MCI gives a value between 0 and 1 where higher values indicate a higher circularity. Examples for complementary risk indicators include material price variation, material supply chain risks, material scarcity and toxicity. Complementary impact indicators can include, for example, energy usage and CO_2 emissions.

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Another challenging aspect is the upscale of assessment to regional levels. When moving to the regional scale, questions regarding the optimal spatial arrangement of land use (e.g. placement of reserves or vegetative buffers) and interactive impacts of multiple independent decisions made by landholders become most relevant to a wider population of stakeholders (e.g. the downstream effects of land-use management decisions on water quality, local biodiversity loss, and local food security). In addition, at the global scale the focus of analysis shifts between distribution of benefits (e.g. national food security), impacts of agricultural production (e.g. global biodiversity loss, climate change) across countries and continents and market forces (including international trade).

In January 2000, the European Commission identified the need for a set of agri-environmental indicators to track the integration of environmental concerns into the CAP at EU, national and regional levels. The Commission is currently working on the development and improvement of 28 agri-environmental indicators. These indicators are giving EU statistic information on the state of different agricultural inputs (e.g. mineral fertilization and pesticides consumption, livestock and crop patterns, land use change…) and environmental aspects such as nutrient and pesticide pollution, greenhouse gas emission. The potential application of agri-environmental indicators for assessing progress in the integration of environmental concerns into the Common Agricultural Policy is still limited due to the complex links between policy measures, changes in farming practices and environmental improvements, and other numerous other intervening factors.

In the context of LCA studies, a new LCA-based approach called "territorial LCA" has gradually emerged to assess geographically or administratively defined systems. Territorial LCAs, which in turn could be divided into two main approaches: i) type A, which focuses on the assessment of a specific activity or supply chain anchored in a given territory; and ii) type B, which attempts to assess all production and consumption activities located in a territory, including all environmental pressures embodied in trade flows with other territories (Loisseau et al., 2018).

The selection of benchmarking indicators, which could provide an integral but simplified information including aspects of environmental, economic and social indicators, represents an important challenge mainly because the different scale and units of specific indicators seen in the previous section, but also due to subjectivity in the weighing or importance of the different perspectives. For the environmental indicators, the PEF initiative has suggested a list of normalisation and weighting factors However, agreement has not been settled for the set of sustainability indicators.

We suggest dealing with the evaluation and ranking of conflicting criteria under the umbrella of Multi-criteria decision analysis (MCDA). MCDA is a widely used method within the frame of natural resource management (Mendoza and Martins, 2006), where multiple indicators or factors should be considered. One obvious advantage of the method is its structured and rational approach to comprehensively and transparently deal with multi-functionality and multiple stakeholders. The MCDA further has a great potential as a decision and communication platform facilitating the handling of factors not presented in similar units and, thus, it is strategy that will be adopted in the Nutri2Cycle project to address the sustainability of the technologies selected for nutrient recovery in agriculture.

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3. Practical selection and calculation of indicators

Within the Nutri2Cycle project technologies have to be assessed based on different availiability of information, because the assessments have to be done for different purposes and at different times in the project, but also because the technologies or solutions are at very different TRL levels or research lines such as biobased fertilisers, novel animal feeds, higher-precision fertilization tools. In Deliverable 3.1. we will conduct a first qualitative screening of the selected dashboard indicators. This work will be based on the review conducted in the current deliverable, but subsequently more advanced assessments will be done on fewer solutions employing LCA, CBA and social LCA approaches (Deliverable 3.3 and 3.4). These assessments will be based on very different foundations in terms of data and models used. Therefore three levels of assessment are proposed:

Level 1: Qualitative/semi-quantitative assessment, where the indicator estimates are based on expert knowledge about possible effect of the introduced technologies.

Level 2: Semi-quantitative assessment, where indicator estimates are based on default global or national emission factor approaches and estimates of relative reductions in emissions. Emission accounting should be based on the IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 2006) and corresponding update (IPCC, 2019), which provide methodologies for estimating national inventories of greenhouse gases, the EEA Report No 13/2019 (Ntziachristos, L., & Samaras, Z. (2019) and the PEFCR guidelines for Environmental Footprint reporting (PEFCR 2018).

Level 3: Quantitative assessment based on advanced modelling approaches and experimental results/measured data from specific technologies allowing the effect of technologies on indicators to be estimated in different regions of Europe. The modelling approaches to assess the impact of the technologies on emissions are described in further detail in Deliverable 1.2.

In the Nutri2Cycle project, we are mainly interested in environmental and economic performance in relation to C, N, P flows. Information provided by agronomic indicators, such as NUE, provide useful information from an agronomic point of view. This can be useful in Nutri2Cycle as productivity is closely related to environmental performance. In addition, Nutri2Cycle will use more specific sustainability indicators, such as indicators based on quantifying emissions to air, soil and water and raw resource consumption in relation to C, N, P flows, which are also supported for several initiatives.

While existing models and different approaches could be applied to deal with the different aspects of sustainability separately, we are aware of the challenges to incorporate the different pillars of sustainability into single integrated indicators. The selection and aggregation of benchmarking sustainability indicators represents an important challenge due to the different scopes, units used, and scales ranging from farm to regional level. None of the existing initiatives provides a clear scheme on how to deal with weighing and ranking criteria for the different aspects of sustainability. This will be addressed under the umbrella of Multi-criteria decision analysis in the Nutri2Cycle project.

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4. Conclusions

The main objective of applying various levels of sustainability indicators in the Nutri2Cycle project is to provide clear information on the degree of improvement in the three pillars of sustainability (environmental, economic, and social aspects) for the innovative technologies proposed. We have performed a literature review on sustainability & performance indicators related to CNP flows. The selection of indicators has been aligned with existing initiatives, mainly European ones, which will make it easier for further comparisons of our technologies with reference values and other studies. We selected a set of indicators, including agronomic indicators, emission/resource commodity consumption-based indicators, environmental indicators, economic indicators and social indicators.

For environmental indicators we will follow the Product Environmental Footprint, PEF (EU, 2018) recommendations in relation to impact assessment models to be applied. Although the environmental assessment should ideally be done for all impact categories, we will focus on a selection of impact categories that are most relevant for the solutions that address the C, N and P flows, for increased applicability and comprehensiveness of the results. Based on recommendations from sectorial PEF Category Rules, we decided a compulsory inclusion of climate change, acidification, eutrophication and fossil resource depletion in the LCA results. The related environmental indicators are shown in Table 8, and these will be used to conduct the preliminary qualitative assessment of technologies in Deliverable3.1. The LCA approach and results will be elaborated later in the project in Deliverable 3.4.

Table 8. 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	Nitrate (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

Impact category	Indicators	Aspect covered
	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

Economic indicators are not only relevant at farm scale but also at more macro scales, such as regions. In regards, to measure viability and profitability, the main economic indicator is the effect on the farmer's income. The income of a farmer depends on a number of other microeconomic indicators such as prices, costs, agricultural production and yields, market indicators (e.g. changes in human consumption) and subsidies (e.g. CAP pillar I and pillar II payments), which are influenced by macroeconomic indicators (e.g. GDP growth, exchange rates). These income results will allow us to analyse the overall production and trade impacts on a regional scale, and ultimately aid in designing appropriate policies.

Social indicators are still at preliminary stage of development with no consensual approach and lack of databases to assess some of the categories. In spite of different nuances, the need to consider the different stakeholders such as workers, local communities, small-scale entrepreneurs and users, becomes evident. Being aware of the difficulties in the current proposals and the existing data gaps, one of the aims of the Nutri2Cycle is to spread the inclusion of social indicators and to provide assessments in agricultural projects, with special attention on consumer acceptance of new technologies. This work will be further elaborated in Deliverable 3.4.

Because of the very different situations with regards to data availability for the different technologies in the Nutri2Cycle project we propose three levels of assessment qualitative/semiquantitative and quantitative. In the current deliverable we have provided the guidance on how to calculate/estimate indicators at TIER 1 or 2, based on existing international guidelines, such as the PEF and IPCC. In Deliverable 1.2 the specific emission models are described that can calculate the emission indicators at TIER3 level.

From the review of the integrated sustainability indicators, we conclude that currently no widely accepted framework to derive an overall score on sustainability is available yet. The PEF initiative has suggested a list of normalisation and weighting factors, however, no agreement has been settled yet for the set of sustainability indicators. Therefore we will use Multi-criteria decision analysis (MCDA) for the evaluation and ranking of the solutions, which offers an approach to deal with potential conflicting criteria. MCDA will be used to synthetize the potential of the Nutri2Cycle solutions to effectively close nutrient loops, considering environmental costs, economic and social dimension and potential of implementation in the EU context.

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