Nutri2Cycle

D3.1 Report on environmental performance indicators for 1st Tier and 2nd Tier of investigated solutions

Deliverable: Report on environmental performance indicators for 1st Tier and 2nd Tier of investigated solutions

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Abbreviations

DBI:	Dashboard indicators
LCA:	Life Cycle Assessment
N_2O:	Nitrous oxide
NH_3:	Ammonia
CFP:	Carbon Footprint
REC:	Non-renewable energy consumption
REP:	Renewable energy production
RP:	Rock phosphate
WT:	Water
OI:	Oil
NG:	Natural gas
NO_3:	Nitrate
P:	Phosphorus
PM:	Particulate matter
SQ:	Soil quality
NR:	Nutrients recovered
CH_4:	Methane
IQV:	Index of qualitative variation

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Glossary

Anaerobic digestion: process through which microorganisms break down organic matter—such as animal manure, wastewater biosolids, and food wastes—in the absence of oxygen.

Biobased fertilisers: substances containing variety of microbes having the capacity to enhance plant nutrient uptake by colonizing the rhizosphere and make the nutrients easily accessible to plant root hairs.

Dashboard indicators: a comprehensive, easy view of metrics that are important to define a technology, project, or initiative**.**

Digestate: material remaining after the anaerobic digestion (decomposition under low oxygen conditions) of a biodegradable feedstock. Anaerobic digestion produces two main products: digestate and biogas.

Life cycle assessment: methodology for assessing environmental impacts associated with all the stages of the life cycle of a commercial product, process, or service.

Method Delphi: a forecasting process framework based on the results of multiple rounds of questionnaires sent to a panel of experts. After each round of questionnaires, the experts are presented with an aggregated summary of the last round, allowing each expert to adjust their answers according to the group response.

Organic waste: Organic waste is any material that is biodegradable and comes from either a plant or an animal.

Precision fertilisation: this is a farming management concept based on observing, measuring and responding to inter and intra-field variability in crops

Primary resources: Resources that exist without any actions of humankind.

Soil enhancer: product which is added to soil to improve the soil's physical qualities, usually its fertility (ability to provide nutrition for plants) and sometimes its mechanics

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1. Executive Summary

Dashboard indicators (DBI) aim to provide a rapid overview of relevant indicators regarding environmental performance of the technologies/solutions for increasing nutrient efficiency, recovery and recycling developed at Nutri2Cycle project. The criteria established to select those indicators was based on the most relevant environmental aspects in relation to nutrients' recovery, recycling and use efficiency in the agriculture and livestock sector (see Deliverable 1.1). DBI should convey relevant information about the environmental performance, being an effective way to benchmark suggested solutions against a baseline (i.e., current situation).

A description of the main technical and environmental features in relation to the selected dashboard indicators was requested from the respective partners in charge of the different technologies or solutions proposed. In addition, a qualitative assessment was performed through a preliminary survey where partners were asked to provide a valorisation of the improvement (or not), expected in relation to a reference situation, for the proposed Nutri2Cycle technology or solution, using the dashboard indicators selected from the earlier described full list of potential indicators (Deliverable 1.1). From now on, for terminology consistency, all technologies and solutions will be referred to as technologies.

As a result, Nutri2Cycle technologies were qualitatively assessed based on a qualitative dashboard using the dashboard indicators suggested. In addition, it was summarised how the different technologies can potentially contribute to improve environmental side effects.

Almost 50% of the answers provided were related a positive impact of the technology in the indicator, especially, related to 'nutrients recovered', 'carbon footprint' and 'soil quality'. A total 6% of the answers for the indicators were negative, meaning that the technology has a potential to cause a negative impact, mainly linked to 'non-renewable energy consumption', 'nitrous oxide (air)' and ammonia (air) emissions. 28% of the answers were 'neutral', meaning, that no difference it is expected in the indicator, compared to the baseline established. Finally, 16% of the answers were 'unknown', thus, the experts could not provide an adequate response for the indicator regarding the effect of the technology in the baseline which is included. It is important to note that the answers provided by the experts for the technologies are compared to a specific baseline, detailed in Annex A, thus the nature of the indicator can vary according to scenario proposed. Trade-offs identified were mainly related to the use of organic fertilizers and potential gases emissions (ammonia and nitrous oxide), and the use of 'non-renewable energy consumption' for the technologies that use electricity in the equipment to recover nutrients.

The DBI presented here are not intended to (and must not) replace more complete and detailed evaluations, such as, Life Cycle Assessments (LCAs). Full LCAs will be conducted for some technologies in a different sub-task of the Nutri2Cycle project and reported in deliverable D3.4. Although LCA is the reference method to perform environmental assessments, due to its comprehensiveness, LCA requires extensive data and complex calculations. Thus, the dashboard indicators rather provide a first screening and rapid appraisal, but, again, they can under no circumstances substitute full LCAs.

Moreover, the current deliverable is focusing on qualitative assessment of the environmental dashboard indicators selected from at Deliverable 1.1. A final assessment of suitability of the technologies will be completed with other relevant criteria, TRL, stakeholder involvement, and a socioeconomic assessment (Deliverables D3.2 and D3.4).

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2. Introduction

The goal of the current deliverable is to preliminary test in a qualitative way the subset of indicators selected in D1.1, allowing to collect data about agro-technical technologies selected in Nutri2Cycle, to be translated into a simplified but comprehensive set of qualitative indicators. These indicators are called dashboard indicators (DBI) and should convey relevant information about the environmental performance of the suggested technologies. A set of DBI can be an effective way to benchmark against a baseline (i.e., current situation). As such they should be easily calculated or assessed, understood, and communicated.

Dashboard indicators aim to provide a first environmental marker of the suitability and applicability of the technologies for increasing nutrient efficiency, recovery and recycling developed in the project. The application of existing and widely applied (in environmental studies) indicators should be a priority rather than defining new indicators. That means DBI cover aspects related to natural resource consumption (i.e., land and water, non-renewable minerals), nutrient cycling (i.e., N, P, C) and energy (i.e., electricity and fuels) and significant emissions to air (NH_3, N_2O, CH_4) and water (NO_3 and P).

In the current deliverable, we provide a qualitative, and sometimes prospective, estimation of these indicators. Ideally, the corresponding indicator values should be measured or quantified during the execution of the project, at the farm or field level.

The dashboard indicators will be developed based on:

1. The different classification of indicators provided in Deliverable D1.1 (D1.1), among them we have selected those that, because of their relevance and simplicity, could be a useful dashboard indicator.
2. Data collection guidance provided in Deliverable D1.2.
3. The existence of reference values to be related to Agri-environmental indicators and Common Context Indicators for Rural Development programs (see deliverable D1.1

The existence of reference values to be related to Agri-environmental indicators and Common Context Indicators for Rural Development programs (see deliverable D1.1)

Subsequently, the overall assessment and grouping dashboard indicators is applied to test the environmental performance of the 44 technical and management technologies for farming systems selected in Deliverable 2.2 and will be used to select, together with other criteria, the demo lighthouse/pilot actions.

The current deliverable has been organized in four sections, containing eight subchapters, and an annex (Annex A). The description of indicators is presented in subchapter 3.1 summarizing the potential environmental consequences of the adoption of the technologies and how they address issues in agricultural and livestock system production. Subchapter 3.2 explains how the collection of dashboard indicators have been organized between the different alternative technologies, the excel-questionnaire prepared and the criteria to fill the data required.

The following chapter, Chapter 4, shows the results of applying the selected environmental DBI in the assessment of the technologies. The results are presented by ‘dimension’ in sections 4.1.1 to 4.1.3. Subchapter 4.2 presents results by research line, describing the potential impacts, and a statistical analysis of variation for qualitative assessments. In subchapter 4.3, potential trade-offs that can occur with the inclusion of the novel technologies is presented.

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Finally, Chapter 5 provides conclusions about suitability of the dashboard indicators used and preliminary environmental consequences of the 44 technical and management technologies proposed.

The current deliverable is focusing on the qualitative assessment of environmental dashboard indicators, the final assessment of suitability of selected technologies should be completed with other relevant criteria, including TRL, stakeholder involvement and a socioeconomic assessment (Deliverables D3.2 and D3.4). Annex A contains the information provided by different technologies experts.

It is important to highlight that dashboard indicators are not intended to replace completer and more detailed environmental studies, such as Life Cycle Assessments (LCA), that will be conducted in a different task of the Nutri2Cycle project and reported in the deliverable D3.4. LCA is the reference method to perform environmental assessments. However, because of its comprehensiveness LCA requires extensive data and complex calculations, and the DBI seems to be a fair and acceptable option for a first screening and rapid appraisal of the technology, making it possible to identify potential hotspots that should be paid more attention when full assessments are carried out. Additionally, other sustainability criteria, such as socioeconomic ones will be assessed providing a comprehensive and multicriteria sustainability and feasibility vision of the technologies by the end of the project (Deliverable 3.4).

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3. Material and Methods

3.1 Definition of the Dashboard Indicators (DBI)

Deliverable 1.1 provided a review of several typologies of indicators that could be useful to assess the technologies and a selection of thirteen indicators (see table ES1) that have a high potential to provide a better overview of the technologies used in the project Nutri2Cycle. In this deliverable, the set of indicators of Deliverable 1.1 was updated to fifteen indicators, and it will be tested/applied aiming to improve sustainability and to close the nutrient (nitrogen, carbon and phosphorus) loops in arable and livestock production systems.

Next sections provide a description of indicators selected, highlighting why those indicators are essential in the assessment of the technologies included in the project. . The dashboard indicators (DBI) are divided in three dimensions:

1. Use of primary resources: Rock phosphate, natural gas, oil, water, nutrients recovered
2. Emissions to the environment: Ammonia (air), nitrous oxide (air), methane (air), nitrates (water), phosphorus (water), particulate matter (PM_{10})
3. Resilience to climate change: Carbon footprint, non-renewable energy consumption, soil quality and renewable energy production.

These three dimensions are used to show results obtained and to create the dashboards for setting the scene for easy-to-use communication towards policy makers, end-users and other stakeholders. It should be noted that as a primary criterion, the technologies must contribute positively regarding agriculture and livestock production, when possible decreasing potential environmental impacts to ensure the sustainability of the systems.

3.1.1 Use of primary Resources

3.1.1.1 Rock Phosphate

Phosphorus is one of the essential nutrients for plants, animals and humans. Currently phosphorus is a critical global resource, alongside water and energy resources. Around 90% of the phosphate rock extracted globally is for food production (Cordell et al. 2009). Most of the world's agricultural fields today rely on fertilizers derived from phosphate rock.

Phosphate rock is a non-renewable resource that has taken 10-15 million years to form from seabed to soil via tectonic uplift and weathering. While there is some uncertainty about the timeline, it is a fact that the quality of remaining phosphate rock is declining (Cordell et al., 2009; Cordell and White, 2011; Steiner et al., 2015). That is, the concentration of P in mined phosphate rock is decreasing and the concentration of unwanted clay particles and heavy metals like cadmium are increasing. The cadmium content of phosphate rock can be very high (maximum allowed by the EU nowadays is of 40 mg cadmium per kilogram of phosphate fertilizer), and this is either considered a harmful concentration for application in agriculture or energy requirements to clean up (Cordell and White, 2014). In addition, phosphates are mainly mined outside EU, which results in high production and transportation costs, also linked to oil prices, and concerns for geopolitical instability and independence. Nowadays, different phosphorous concern initiatives (e.g. European Sustainable Phosphorus Platform, ESPP,2020, EU-Agri-

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environmental Indicators, EU-AI, 2020) are going on in Europe. Therefore, the 'Reduction of mineral phosphorus consumption', or 'Rock phosphate', has been chosen as a dashboard indicator.

3.1.1.2 Natural Gas

Nitrogenous fertilisers (ammonia, urea, ammonium nitrate) are produced from natural gas, whose price is strongly linked to oil prices, and elemental N_2 from air. The consumption of fossil fuels (such as oil products and natural and derived gases) leads to resource depletion and emissions of greenhouse gases (EEA 2020). The reduction of mineral fertilizer consumption and corresponding dependence decrease on fossil fuels is another goal for the technological technologies provided by the Nutri2Cycle project. Thus, the indicator 'Reduction of natural gas consumption', or 'Natural Gas' was selected as a DBI.

3.1.1.3 Oil

While the previous indicator (primary resource) has been mainly related to nitrogenous and phosphorus fertilizers production, oil consumption is mainly linked to the fuel use of agricultural machinery (e.g. cultivation of fields with tractors). Oil and petroleum products contributed to 53 % of total energy consumption by agriculture in the EU-28 in 2017 and were the main fuel type used in most of EU countries (EU-AI, 2020). Those Nutri2Cycle project technological technologies, which provide a reduction of tillage, or sowing or harvesting practices as well as a reduction of transport, both in distance and volume transported will be prioritized. Therefore, the 'Reduction of oil consumption in agricultural machinery', or 'Oil', was selected as a DBI.

3.1.1.5 Water

Irrigation water use is a major driving force behind water abstraction globally. In the EU, the agricultural sector accounts for 46 % of the total annual water use in average, of which most is used in southern Europe (around 90 %)(EU-AI 2020).

Here, water abstraction at unsustainable rates occurs when the demand for water exceeds the amount available during a certain period. In the coming years, climatic conditions like a decrease in precipitation in southern Europe associated to the lengthening of the thermal growing season, may lead to a slight increase in water requirement for irrigation. Consequently, 'Reduction of water consumption', or 'Water', is also an aspect to be considered in Nutri2Cycle alternatives technologies, which justifies its inclusion as a DBI.

3.1.1.7 Nutrients recovered

The excess of nutrients in the environment is a major source of air, soil and water pollution, negatively impacting biodiversity and climate. The European Commission is expecting to reduce nutrient losses by at least 50%, while ensuring no deterioration on soil fertility and reduce fertilizer use by at least 20% by 2030 (European Commission, 2020).

Importantly, we are in Nutri2Cycle looking at the impact of technologies on overall resource substitution (Figure 1), not just the direct recovery of N or P, but more how the solution improves the overall utilisation of nutrients (both recovered and primary nutrients in fertilisers) for agricultural production and reduces losses to the environment.

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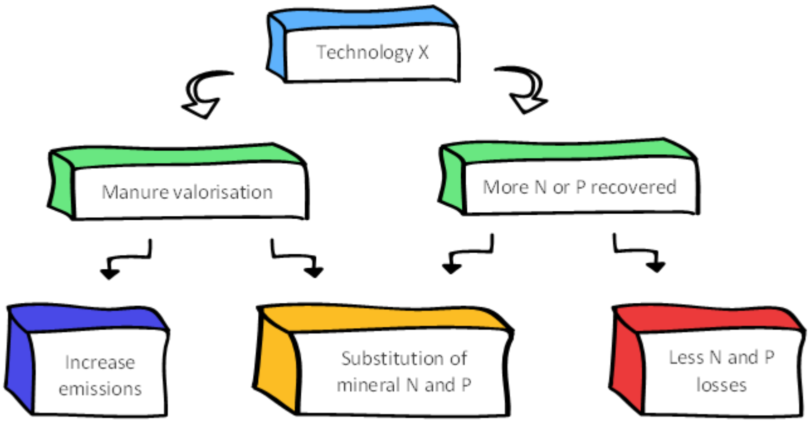

Figure 1. Example how the technologies can impact on nutrient recovery

Therefore, since 'Nutrients recovered' is the major goal in Nutri2Cycle project, the indicator is essential to be included to assess the novel technologies.

3.1.2 Emissions to the environment

3.1.2.1 Ammonia (air emission)

EU-28 agricultural sector emitted a total of 3 751 kilotons of ammonia (2015) and was the responsible for 94% of total ammonia emissions across the region (EU-AI, 2020). 'Ammonia emission' is contemplated as one of the Agri-environmental indicators of the EU (EU-AI, 2020), and was also suggested in the Sustainable Development Goals of United Nations, SDG 2: End hunger, achieve food security and improved nutrition and promote sustainable agriculture. Therefore, the indicator 'Reduction of ammonia emissions', or 'Ammonia (air emission)', was included in the DBI.

3.1.2.2 Nitrous oxide (air emission)

Nitrous oxide (N_2O) is a potent greenhouse gas with a 100-year global warming potential 298 times greater than carbon dioxide (Roughan et al. 2018). Agriculture contributes to these emissions mainly due to nitrogen fertiliser use and emissions from animal waste. Its contribution is accounted for the national GHG inventories, and it is also considered as one of the indicators to Sustainable Development Goals of United Nations, SDG 13: Take urgent action to combat climate change and its impacts. Therefore, 'Reduction of nitrous oxide emission', or 'Nitrous oxide' (air emission) was selected for the DBI.

3.1.2.3 Methane (air emission)

Methane (CH_4) is a greenhouse gas, coming mainly from enteric fermentation of ruminants and manure decomposition. Methane is also comprised in the national GHG inventories, and it is one of the indicators to Sustainable Development Goals of United Nations, SDG 13: Take urgent action to combat climate change and its impacts. Thus, 'Reduction of methane emission', or 'Methane (air emission)', is one of the DBI selected in the present work.

3.1.2.4 Nitrate (water emission)

Agriculture is, in general terms, the greatest contributor (50 - 75 %) to nitrate levels in freshwater across Europe. Legislation has been established to address this issue since long time ago, the

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nitrate in freshwater from agricultural sources is addressed by the Nitrates Directive (EEC, 1991). The Nitrates Directive requires the establishment of Nitrate Vulnerable Zones (NVZ) in areas where agricultural sources of nitrate have led or could lead to excessive concentrations in surface freshwater and groundwater or threatened waters sensitive to eutrophication. Action programmes are required for NVZ that detail a range of measures that need to be implemented to prevent and reduce nitrate pollution. Nitrates water emission is one of the indicators to Sustainable Development Goals of United Nations, SDG 6: Ensure availability and sustainable management of water and sanitation for all. Therefore, 'Reduction of nitrate emission', or 'Nitrate (water emission)', was one of the selected DBI.

3.1.2.5 Phosphorus (water emission)

Phosphorus is an important plant nutrient, essential for world-wide food security. As said before, it is used in agriculture as fertiliser, and the EU is strongly dependent on imports to fulfil its need. However, phosphorus has been used in an unsustainable way; via over-application of fertilisers, sewage and animal manure larger than crop demand and offtake, leading to loss of phosphorus and other nutrients to water bodies and causing pollution and eutrophication (Ngatia & Taylor 2018). The vulnerability to phosphorus leaching, or P-sensitivity, refers to the combined risk of phosphorus loss to the surface waters by combinations of low sorption capacity, high erosion risk and increased risk of runoff or drainage. It is also one of the indicators to Sustainable Development Goals of United Nations (SDG 6). The contribution of agriculture to the phosphorus loads in surface waters is estimated by the EEA between 20 and more than 50% and includes both point sources (wastewater from farms and seepage from manure stores) and diffuse contamination (agricultural land). Therefore, the 'Reduction of phosphorus emission', or 'Phosphorus (water emission)' will be used as a DBI.

3.1.2.6 Particulate matter (air emission)

Particulate matter (PM) emissions to air (directly and indirectly via ammonia emissions) contributes to stratospheric ozone depletion, acid rain and smog, and it has a main influence on human health through impacts on respiratory and cardiovascular diseases (Losacco & Perillo, 2018). Also, it has influence on the climate, making difficult the global energy balance, since PM is made up of many different chemical properties, which some lead to warming of temperatures by absorbing heat from the sun, whilst others bring about cooling effects by reflecting sunlight (Law, 2010). PM is one of the indicators to Sustainable Development Goals of United Nations, SDG 11: Make cities and human settlements inclusive, safe, resilient and sustainable, also is one of the Agri-Environmental Indicators (AEI). Therefore, 'Reduction of particulate matter production', or 'Particulate matter' will be applied as DBI for the Nutri2Cycle technologies.

3.1.3 Resilience to climate change

3.1.3.1 Carbon footprint

Climate change is increasing the frequency and intensity of the extreme weather and climate events that are affecting all countries. In Europe, out of the total GHG emissions in 2017, 10 % was emitted by the agricultural sector. Over the time span 1990 to 2017, the sector reduced its emissions by 104 million tonnes of CO_2-equivalent, which corresponds to -19 % compared with 1990. However, it is already on track to meet its greenhouse gas emissions reduction target for 2020, and the most ambitious goal that links energy sources and infrastructure to support

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decarbonisation and build a climate neutral EU by 2050. EU's greenhouse gas emission reductions target for 2030 to at least 50% and towards 55% compared with 1990 levels in a responsible way (EU, 2020). Trough the carbon footprint (CFP) indicator it is estimated the overall amount of GHG emitted from a product or activity considering its life cycle (Rebolledo-Leiva et al, 2017). The methodology to calculate CFP is standardized in the ISO 14067:2018 (ISO 14067, 2018). Therefore, 'Reduction of carbon footprint', or 'Carbon footprint', is a good indicator to ensure technologies developed on Nutri2Cycle project are in line with EU requirements.

3.1.3.2 Non-renewable energy consumption

Regarding electricity consumption, the reduction of non-renewable energy consumption is a critical aspect of improving sustainability of agri-food sector, at least as long as electricity is mainly produced from fossil energy. Current European Green Deal (EC, 2019) stresses the need to rethink policies for clean energy. In accordance with that, new technologies shall ensure the reduction of electricity consumption and/or use of cleaner energy, preferably both. Therefore, it is of high relevance to include 'Non-renewable energy consumption' in the indicator set for the DBI.

3.1.3.3 Soil quality

Soil is a valuable, non-renewable resource that offers a multitude of ecosystems goods and services. Its preservation is considered in the frame of SDG 15: Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss. Soil quality is defined in as the "capacity of a living soil to function, within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and promote plant and animal health". Soils deliver essential ecosystem services, such as freshwater purification and regulation, food and fibres production and maintain the global ecosystem functions as well. Ensuring the maintenance of high-quality standards for the state of soils is therefore a fundamental requirement for global sustainability (Doran, 2002). Hence, it is expected that those Nutri2Cycle technologies, which include the addition of effective organic matter (see section 3.1.3.2) will contribute to achieve these. Therefore, improvement on soil quality and arresting soil degradation, were included in 'Soil quality' as an indicator in the Nutri2Cycle environmental dashboard.

3.1.3.4 Renewable energy production

Energy consumption from non-renewable has been seen as a problem of resources that causes resource depletion and pollution. Natural Gas and Oil consumption has been defined as indicators as they are seen as resource depletion and contributing to pollution. Therefore, the ''Renewable energy production', (e.g. biogas) will be estimated as positive aspect of Nutri2Cycle project technologies. Moreover, this is one of the indicators to Sustainable Development Goals of United Nations, SDG 7: Ensure access to affordable, reliable, sustainable and modern energy for all.

3.1.3.5 Overview of Dashboard Indicators

The three dimensions established, and the indicators selected are summarized Table 1. It is highlighted also their relations to the goals and indicators addressed in the international

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agreements for sustainability: Sustainable Development Goals (SDGs), Agri-environmental indicators (AEI) and the European Green Deal (EGD).

Table 1. Dimensions and indicators selected for the Nutri2Cycle project dashboard

Dimension	Indicator	Intended positive change	In agreement with...
Use of primary resources	Rock phosphate	Reduction of mineral phosphorus consumption	AEI, SDG 12[g]
	Natural gas	Reduction of natural gas consumption in mineral fertilizers production	AEI, EGD, SDG 12[g]
	Oil	Reduction of oil consumption in agricultural machinery	AEI, EGD, SDG 12[g]
	Water	Reduction of water consumption	AEI, SDG 6[d]
	Nutrients recovered	Nutrient recovered from agriculture and livestock systems	AEI, EGD
Emissions to environment	Ammonia (air)	Reduction of ammonia emissions	AEI, EGD, SDG 2[b]
	Nitrous oxide (air)	Reduction of nitrous oxide emissions	AEI, EGD, SDG 13[c]
	Methane (air)	Reduction of methane emissions	SDG 13[c]
	Nitrate (water)	Reduction of nitrate emissions	AEI, EGD, SDG 6[d]
	Phosphorus (water)	Reduction of phosphorus emissions	AEI, EGD, SDG 6[d]
	Particulate matter (PM_{10})	Reduction of particulate matter formation	EGD, SDG 11[e]
Resilience to climate change	Carbon footprint	Reduction of carbon footprint	AEI, EGD, SDG 13[c]
	Non-renewable energy consumption	Reduction of non-renewable energy consumption	AEI, EGD, SDG 7[f], SDG 13[c]
	Soil quality	Improvement on soil quality	AEI, EGD, SDG 15[a]
	Renewable energy production	Renewable energy produced from biomass	AEI, EGD, SDG 7[f]

[a]SDG 15: Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss.
[b]SDG 2: End hunger, achieve food security and improved nutrition and promote sustainable agriculture.
[c]SDG 13: Take urgent action to combat climate change and its impacts.
[d]SDG 6: Ensure availability and sustainable management of water and sanitation for all.
[e]SDG 11: Make cities and human settlements inclusive, safe, resilient and sustainable.
[f]SDG 7: Ensure access to affordable, reliable, sustainable and modern energy for all.
[g]SDG 12: Ensure sustainable consumption and production patterns.

3.2 Alternative technology scenarios assessed

The Nutri2Cycle shortlist contains 44 specific technologies categorised in 24 groups of technologies, and includes nutrient recovery from organic waste, anaerobic digestion, precision fertilisation, treatment of livestock (cattle, pig, or poultry) manure and slurry, or agricultural organic waste.

These technologies produce bio-based fertilisers, either in inorganic form (e.g. N fertilisers produced from nutrient recovery), or as organic products (e.g. digestate, organic soil enhancers). Partners in charge of the different alternative technology scenarios were requested to provide a description of the technologies (Deliverable 2.1) and to assess the main features in relation to dashboard indicators selected (further details in Annex A), these have been grouped by the five research lines established at Nutri2Cycle project (Table 2):

1. Innovative solutions for optimized nutrient & GHG in animal husbandry.
2. Innovative soil, fertilisation & crop management systems & practices.

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3. Tools, techniques & systems for higher-precision fertilization.
4. Biobased fertilisers (N, P) and soil enhancers (OC) from agro-residues.
5. Novel animal feeds produced from agro-residues.

Table 2. Short list solutions compared using the dashboard indicators.

ID Deliverable 3.1	Technology	Name	Research Line
1	RL13.LL10	Small / Farm scale anaerobic digestion	1
2	RL13.LL48	Recovery of energy from poultry manure and organic waste through anaerobic digestion	1
3	RL14.LL61	Tailor-made digestate products (tool development)	1
4	RL15.LL8	Acid leaching of P from organic agro-residues in order to produce OM-rich soil enhancers and P fertilizers	1
5	RL15.LL11	Recycling fibres of manure as organic bedding material for dairy cows	1
6	RL 15. LL24	Adapted stable construction for separated collection of solid manure and urine in pig housing (followed by separate post-processing)	1
7	RL16. LL27	Use of an inoculate of microbiota and enzymatic precursors to reduce ammonia emissions and optimize nutrients use efficiency	1
8	RL17.LL18	Slurry acidification with industrial acids to reduce NH3 volatilization from animal husbandry	1
9	RL17.LL19	Slurry bio-acidification using organic waste products to reduce NH3 volatilization and increase fertilizer value	1
10	RL18.LL32	Annual Nutrient Cycling Assessment (ANCA)	1
11	RL1.LL16	Farm using digestate, precision agriculture and no-tillage focusing on OM stocking in an area characterized by the lack of OM	2
12	RL1. LL17	Crop farmer using a variety of manure and dairy processing residues to recycle and build soil C, N, P fertility	2
13	RL1. LL71	Practices for increasing soil organic matter content in Dutch soils	2
14	RL.2. LL21	Catch crops to reduce N losses in soil and increase biogas production by anaerobic co-digestion	2
15	RL19.LL30	Precision farming coping with heterogeneous qualities of organic fertilizers in the whole chain	3
16	RL20.LL28	Precision farming and optimized application: under-root application of liquid manure for maize and other row crops	3
17	RL20.LL63	Precision fertilization of Maize using organic materials	3
18	RL21.LL73	Precision arable farming using bio-based fertilizers in potato growing	3
19	RL22.LL68	Integration of UAV/Drone and optical sensing technology into pasture systems	3
20	RL23.LL13	Sensor technology to assess crop N status	3
21	RL3.LL14	Closing the loops at the scale of farm: using the livestock manure to fertilize the feeding crop on agroforestry plots	4
22	RL3.LL15	Substituting mineral inputs with organic inputs in organic viticulture	4
23	RL3.LL57	Recovered organic materials and composts for precision fertilization of orchards and vineyards	4

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24	RL3.LL66	Application of digestate in large scale orchards	4
25	RL4.LL1	Ammonium stripping / scrubbing and NH4NO3 as substitute for synthetic N fertilizers	4
26	RL4.LL2	Ammonium stripping / scrubbing and (NH4)2SO4 as substitute for synthetic N fertilizers	4
27	RL4.LL6	Concentrate from vacuum evaporation/ stripping as nutrient-rich organic fertilizer	4
28	RL4.LL9	Liquid fraction of digestate as a substitute for mineral N & K fertilizer	4
29	RL5.LL47	Production of growing substrates for horticulture application from poultry manure, solid state digestate and biochar through composting	4
30	RL5.LL62	Blending of raw and treated organic materials to produce organic fertilizers (NPC)	4
31	RL6.LL49	Nitrogen and phosphorus recovery from pig manure via struvite crystallization and design of struvite based tailor-made fertilizers	4
32	RL6.LL52	Pilot-scale crystallizer for P recovery	4
33	RL6.LL65	Struvite as a substitute of synthetic P fertilizer	4
34	RL7.LL20	Low-temperature ammonium-stripping using vacuum	4
35	RL7.LL23	Pig manure refinery into energy (biogas) and fertiliser using a combination of techniques applicable at industrial pig farms	4
36	RL7.LL43	Pig manure evaporation plant	4
37	RL7.LL55	Manure processing and replacing mineral fertilizers – The Netherlands	4
38	RL8.LL22	BIO-PHOSPHATE: high temperature reductive thermal process recovery of concentrated Phosphorus from food grade animal bones	4
39	RL9.LL40	Insect breeding as an alternative protein source on solid agro-residues (manure and plant wastes)	5
40	RL10.LL25	Soybeans in Kujawsko-Pomorskie and Wielkopolskie voivodships in Poland - innovative solutions in the cultivation, plant protection and feeding on farms	5
41	RL10.LL45	Inpulse: innovating towards the use of Spanish legumes in animal feed	5
42	RL11.LL34	Secondary harvest: additional valorisation of crop harvest and processing residues	5
43	RL12.LL41	Floating wetland plants grown on liquid agroresidues as a new source of proteins	5
44	RL24	Algae grown on nutrient rich liquid agro-effluents as a new source of proteins	5

3.3 Qualitative assessment of the technologies in Nutri2Cycle project

In order to provide the screening assessment for the technologies in the Nutri2Cycle project, a survey on the dashboard indicators was carried out for 44 technologies. Partners in charge of the different individual alternative technology scenarios were asked to provide an assessment and qualitative valorisation of the improvement (or not) expected in relation to a reference situation (baseline) for the different dashboard indicators defined and a brief reasoning justification of the decision (Table 3). The baselines scenario considered for each solution is given in the Annex A. After that, responses were collected and organized in an excel file and sent to the leaders of the five research lines for a review, clarification and confirmation of the answers when they found it necessary.

Table 3. Excel sheet used as a survey to qualitative evaluate dashboards indicators of the different technologies assessed.

Technology						
Brief description of the technology						
Reference baseline against will be evaluated	*Please explain briefly reference scenario used to set the initial situation.*					
Please write down if it is expected a positive, negative or an unknown change when applying the technology for each indicator in relation to a reference scenario with a brief justification						
Dashboard Indicators	Source	Positive	Negative	Unknown	Neutral	Comment your answer
Use of Primary Resources	Rock Phosphate					
	Natural Gas					
	Oil					
	Water					
	Nutrients recovered					
Emissions to the environment	Ammonia (air)					
	Nitrous oxide (air)					
	Methane (air)					
	Nitrates (water)					
	Phosphorus (water)					
	Particulate matter					
Resilience to climate change	Carbon footprint					
	Non-renewable energy consumption					
	Soil quality					
	Renewable energy production					

The procedure to achieve the qualitative assessment is summarized in Figure 2. It is important to highlight that each technology was qualitative assessment for at least 3 experts, including, one from IRTA (main author of this deliverable) (both rounds), the expert responsible of each research line (in the review round), and the expert (s) responsible for each technology (both rounds). Each answer is justified and, when it was possible, literature data was included (Annex A).

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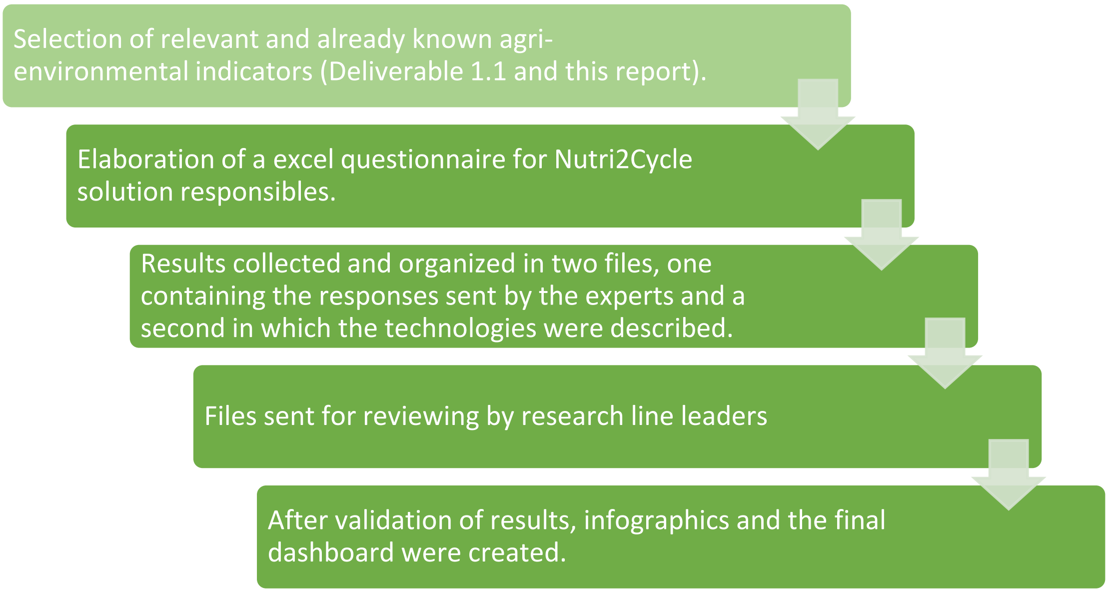

Figure 2. Flowchart summarize the methodology applied in the qualitative assessment of Nutri2Cycle project technologies.

In Table 1, it is defined the statement for each indicator goal, a reduction or an increasing, thus, each indicator is evaluated in relation to the reference scenario (baseline) (see Annex A), using a Delphi method, having as potential answers: a plus (positive impact) or minus (negative impact) in the corresponding reduction/increase; Zero was used if the technology does not apply (neutral impact) and "?" if it is unknown (unknown impact) (Figure 3). Note that with this rapid and initial assessment it was possible to predict the nature of the impact (positive, negative, neutral or unknown), but not the magnitude of impact, that will be assessed, for priority technologies, by the full evaluation with Life Cycle Assessment.

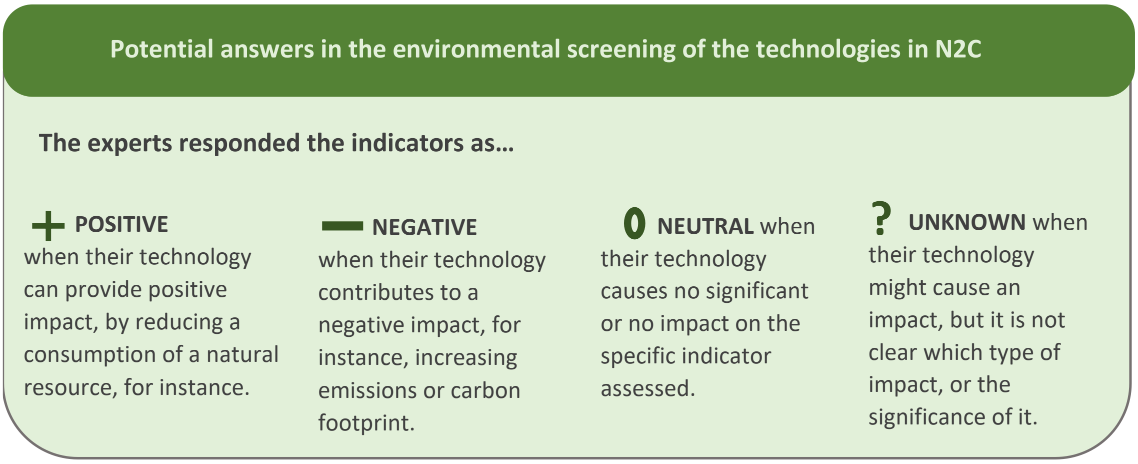

Figure 3. Definition of the codes used for the qualitative assessment of the technologies in the Nutri2Cycle project

In addition, we applied the Index of qualitative variation (IQV) (Agresti & Agresti, 1978) to measure the variability for the nominal variables used to answer the DBI. The IQV is calculated using the following equation:

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$$\text{IQV} = \text{k} * {(100^2 - \sum \text{Pct2})}\big/{(100^2 * (\text{k} - 1))}$$

Equation 1: Equation to estimate variability in the qualitative DBI

where:

IQV = Index of qualitative variation

k = number of categories in the distribution

ΣPct2 = Sum of all squared percentages in the distribution

The index goes from 0 to 1, and the closest is IQV to 1, the higher is the diversity among the answers provided in the indicator. On the other hand, if IQV is 0 (zero), it means that there is no variability in the results. A high IQV means that the impact from the solution on this indicator is highly variable, thus we cannot assume that is a typical impact expected from the Research Line. In the present deliverable, we assumed that an IQV lower than 0.25[1] represents low variation in the potential impact for the indicator, therefore we can assume the answer as a 'typical' impact from the technologies in the research line. On the other hand, an IQV higher than 0.75[2] represents high variation in the potential impact for the indicator. The IQV will be applied for research line and for all set of technologies in each research line of Nutri2Cycle.

Finally, we discuss the 'unknown' and 'neutral' answers and how they can be treated in order to better guide decision-making for end-users and other stakeholders.

It is important to highlight that some positive (or negative) impacts caused can have a higher significance in the environment. For instance, recovering nitrate in Catalonia it is more urgent than recover phosphorus since nitrate in soil is an issue on this area; or water saved has 'less beneficial' impact than reducing N_2O emissions. Thus, it would be necessary applying a methodology for weighting the indicators. European Commission list five types of approaches available (single item, distance-to target, panel-based, monetary valuation and meta-models) and provided their own recommendations for weighting (Sala et al. 2018). Since in the dashboard indicators is provided a qualitative assessment, we decided not including weighting scores for the indicators but providing the nature of the impacts potentially caused and highlight potential trade-offs that can occur in the system. However, if it is intended to apply the guidelines recommended for the DBI in deliverable 1.1., we suggest applying EC weighting factors.

4 Results and Discussion

Sections 4.1 to 4.3 show the evaluation results for the dashboard indicators per Dimension while section 4.4 combines the results by research line. In section 4.5, the DBI are presented as an infographic for setting the scene for easy-to-use communication towards policy makers, end-

[1] 0.25 means that 90% (and more than) of the answers were the same (i.e. 90% of the answer were 'positive'), and the others 10% could be attributed to one answer (i.e 10% of the answers were 'neutral') or distributed by them (i.e. 5% for 'negative', 3% for 'neutral' and 2% for 'unknown')

[2] 0.75 means that around 60% of the answers were the same (i.e. 60% of the answer were 'positive'), and the others 40% or distributed by the other answers (i.e. 20% for 'negative', 15% for 'neutral' and 5% for 'unknown').

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users and other stakeholders, using RL2.LL21 results as an example. Annex A includes a brief reasoning of the detailed assessment/evaluation for each technology.

4.1 Dashboard indicators by dimension

Results presented in this section represent a summary of all technologies. It is also important to keep in mind that the technologies can vary significantly according to climate conditions and management operations, thus results presented are specifically related to the country and conditions (i.e., the baseline) defined by the expert(s) in each technology.

4.1.1 Dimension 1: Use of primary resources

Regarding the use of primary resources, 54% of the answers in this dimension were positive, meaning that the technologies can contribute to reduce harmful effects (e.g. consumption of natural gas) and/or increase beneficial effects (e.g. reduction of water use) (Legend: NR= Nutrients recovered; WT = Water; OI=Oil; NG= Natural Gas; RP = Rock phosphate

Figure 4).

It could be highlighted that 100% of the technologies listed could contribute to increase ‘nutrients recovered’ by providing valorisation of bio-based products and avoiding the use of mineral fertilizers, this is also reflected in the reduction of ‘rock phosphate’ use, for which 64% of technologies shows beneficial contribution. The reduction of mineral fertilizers use agrees with the reduction of ‘natural gas’ consumption (61%) mainly in relation with synthetic fertilizers manufacture, and a reduction of ‘water’ consumption has been pointed out by 30% of technologies assessed. On the other hand, only 14% can provide positive results in ‘Oil’ indicator, meaning that a decrease of oil consumption is expected only in 6 technologies.

No negative answer was pointed to ‘natural gas’.

Regarding neutral responses, the indicator ‘Oil’ received this response for 70 % of the technologies, meaning that the technologies have no significant or no impact on the indicator. The impact on ‘water’ is neutral for 59% of the technologies.

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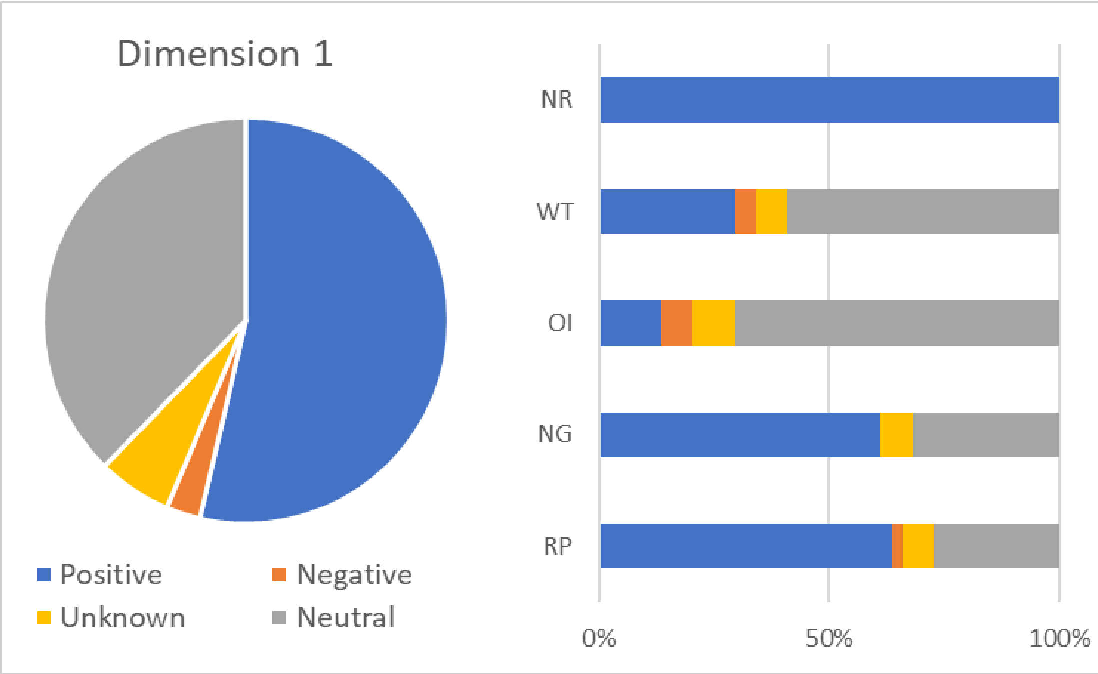

Legend: NR= Nutrients recovered; WT = Water; OI=Oil; NG= Natural Gas; RP = Rock phosphate

Figure 4. Infographic containing a summary of the responses related to the nature of the impact caused by the technologies in the indicators of Dimension 1

Figure 5 shows in detail the responses given by each technology for the indicator selected for DBI in Dimension 1. In Annex A, the responses are described by research line and by technology.

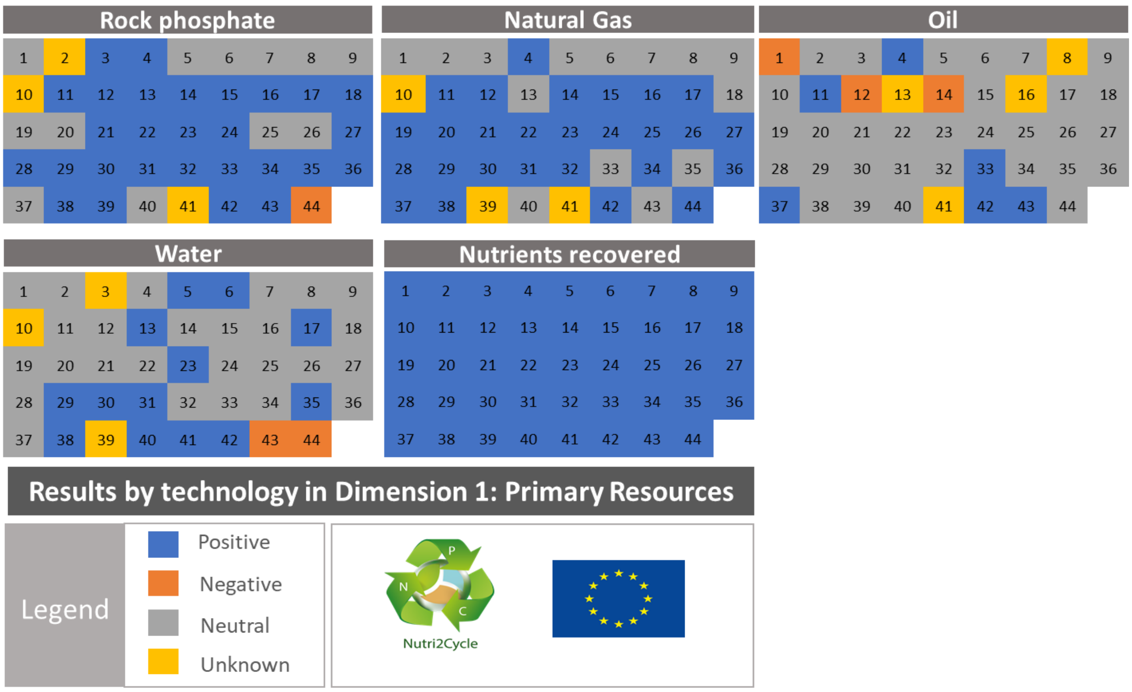

Figure 5. Technologies responses for the DBI aggregated in Dimension 1: Use of primary resources.

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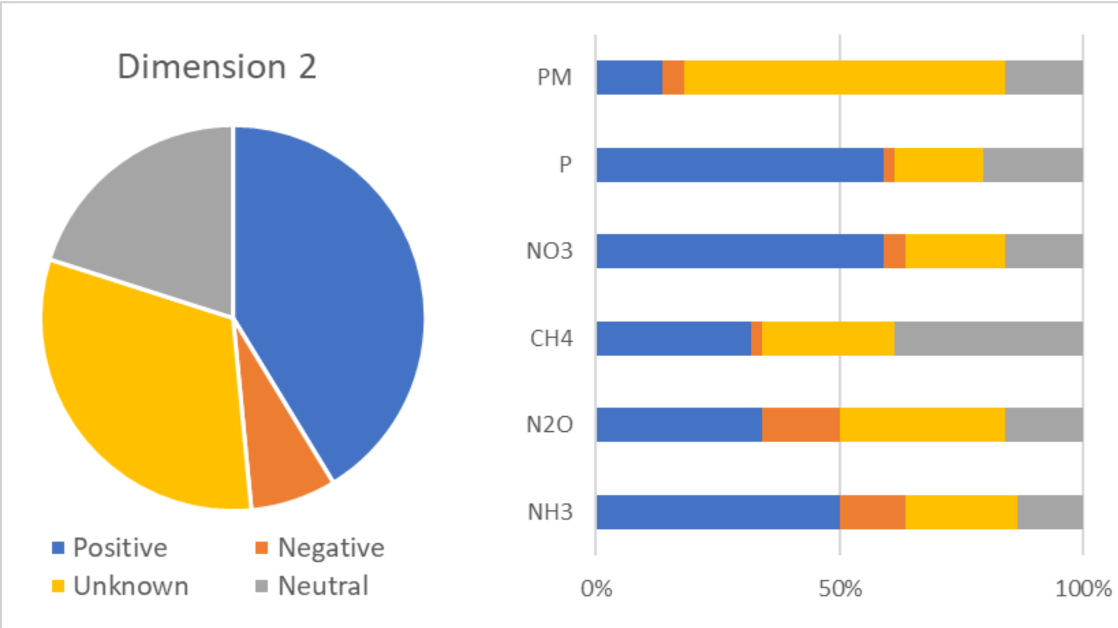
4.1.2 Dimension 2: Emissions to environment

Major contribution of the technologies assessed correspond to the reduction of nitrate and phosphorus leaching to water (59%), followed by reduction of ammonia emissions to air (50%), as far as most of the technologies are related to nutrient recovery. Some technologies have also indicated a reduction of N_2O (34%), CH_4 (32%) and particulate matter (14%) emissions. In Figure 6, the results are summarized according to the responses for each technology. No technology had six positive responses for the indicators in dimension 2, and 78% of the technologies had at least one positive answer.

Regarding individual responses for the indicators (Figure 6), 'Nitrates (water emission)' was the indicator which received more positive answers, 53%, representing 24 technologies. On the other hand, only 14% (6 technologies) can provide positive results in 'Particulate matter'. Regarding negative responses, the indicator 'Ammonia (air emission)' was the one that received more of that, 16% (7 technologies). For neutral responses, the indicator 'methane (air)' received 39% of this kind of answer since several technologies are related to arable land and not livestock. 'Particulate matter' received 'unknown' as answers for 66% of the technologies.



Legend: PM = Particulate Matter; P = Phosphorus (water); NO3 = Nitrate (water); CH4 = Methane (air); N2O = Nitrous oxide (air); NH3 = Ammonia (air).

Figure 6. Infographic containing a summary of the responses related to the nature of the impact caused by the technologies in the indicators of Dimension 2

Figure 7 shows in detail the response given for each technology for the indicator selected for the DBI in Dimension 2.

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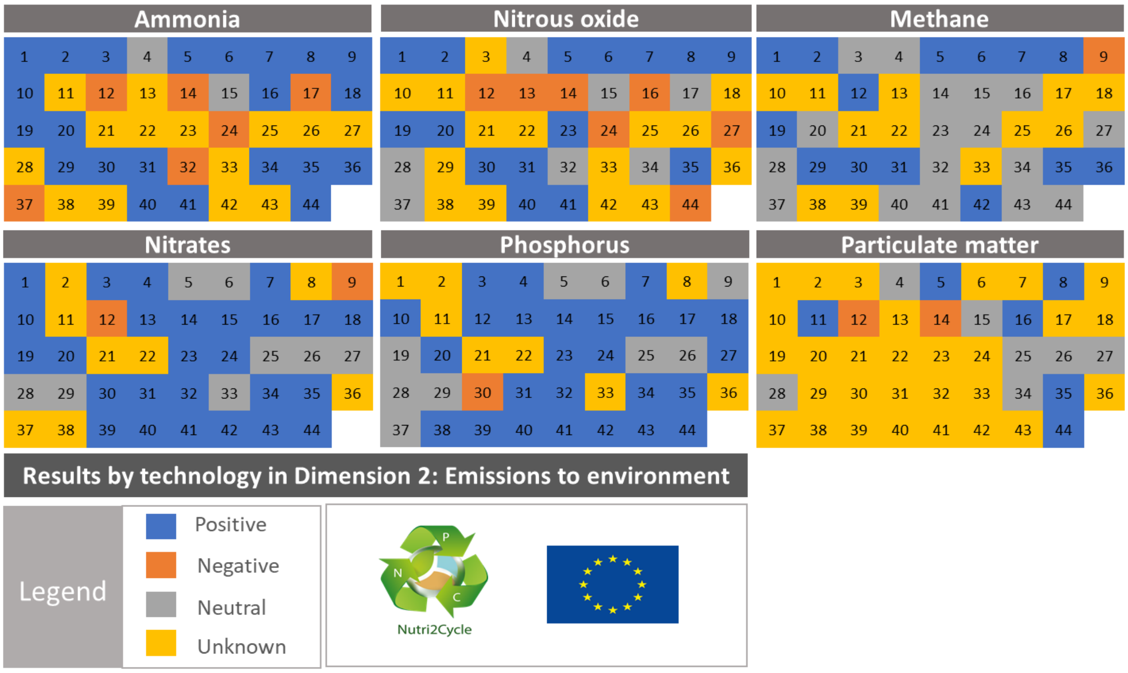

Figure 7. Technologies responses for the DBI aggregated in Dimension 2: Emissions to environment

4.1.3 Dimension 3: Resilience to climate change

In this dimension, most of the technologies assessed (91%) have responded as positive to reduce carbon footprint. The use of biobased products as fertilizers contributes to increase ‘soil quality’ (64%) and soil water retention, and there is an increase of renewable energy production (43%) due to biogas production or the use of wood with energy purpose (Figure 8). Also, it is interesting to highlight that 43% of the technologies result in an increase of effective soil organic matter. In Figure 6, the results are summarized according to the responses provided by the technologies. Regarding negative responses, the indicators and ‘Renewable energy production’ was the only that received more of that, 2% (1 technology). In relation to ‘non-renewable energy consumption’ of some technologies, our results showed an increase of consumption (27%) because the solution needs electricity to operate. For neutral and unknown responses, the indicator ‘Renewable energy production’ received this response for about 52% of the technologies. ‘Unknown’ was responded by 11% of the experts regarding impacts on ‘soil quality’, meaning that there will be an impact, but they are not sure about the nature of the impact in the indicator.

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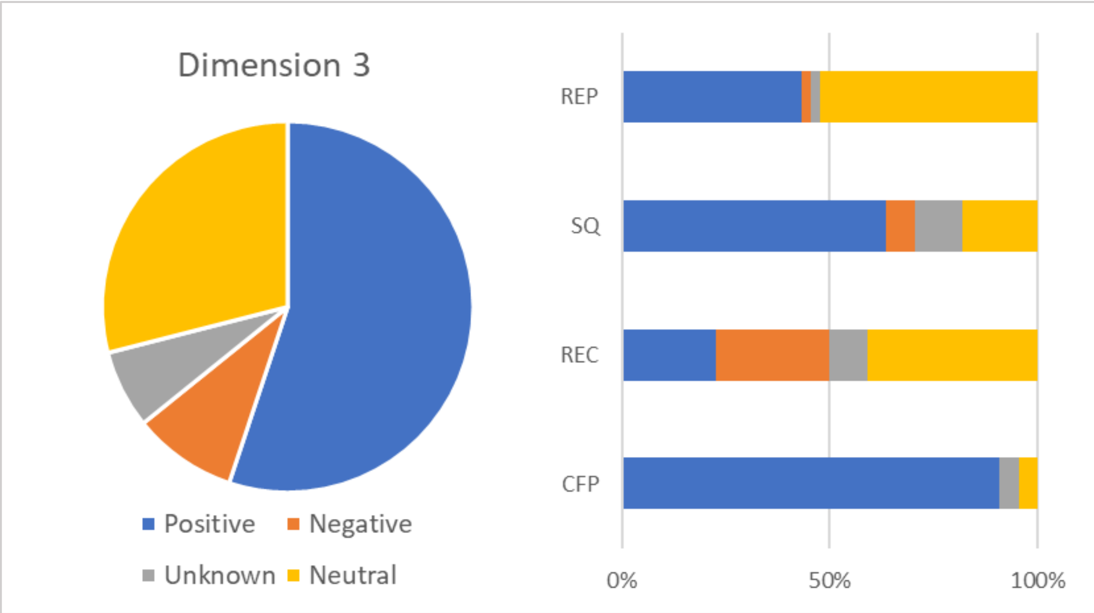

Legend: REP = Renewable energy production; SQ = Soil quality; REC = Non-renewable energy consumption; CFP=Carbon Footprint

Figure 8. Infographic containing a summary of the responses related to the nature of the impact caused by the technologies in the indicators of Dimension 3

Figure 9 shows in detail the response given for each technology for the indicator selected for the DBI in Dimension 3.

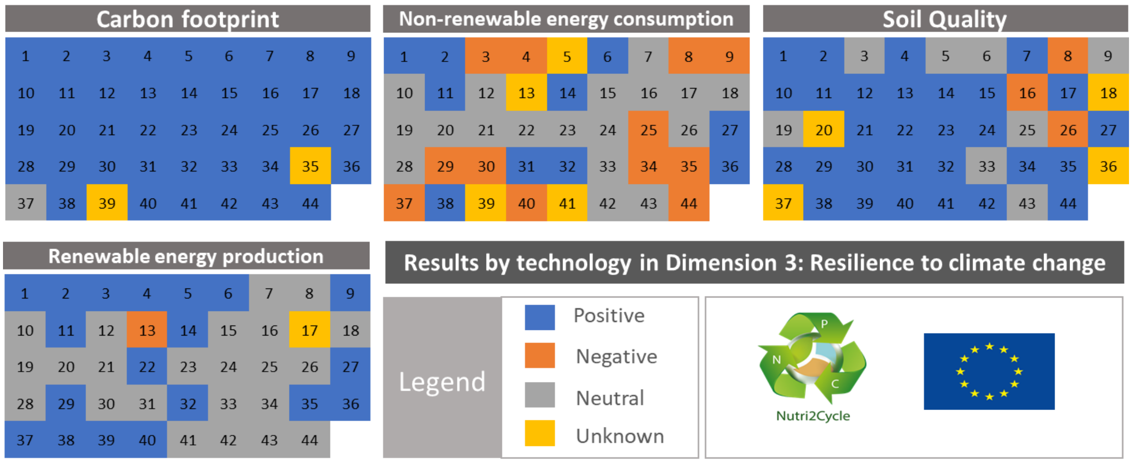

Figure 9. Technologies responses for the DBI aggregated in Dimension 3: Resilience to climate change

4.2. Main aspects by research line

In this document, the results were present considering all technologies, but it is also relevant to highlight the potential impacts by research line. The complete description of the indicators is presented in Annex A.

In Figure 10, results are presented by research line, and will be detailed in the following sections. ‘Nutrients recovered and ‘Carbon Footprint’ are the indicators that most coincide among the lines of research, reaching almost 100% of positive responses. On the other hand, ‘ammonia’ and ‘nitrous oxide’ vary significantly, due to the specificities in each research line.

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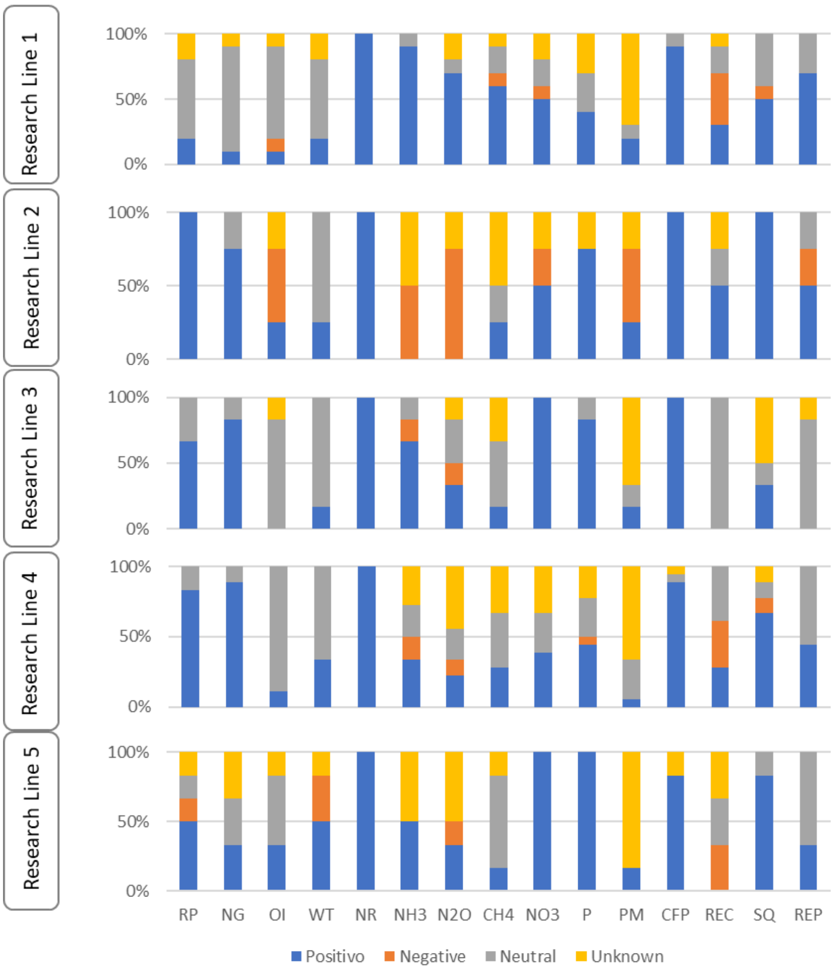
For ‘Neutral’ responses, we should analyse them in more detail. ‘Neutral’ responses, as explained before, were given in the cases that the impact caused by the solution was very similar when compared to the baseline or when no changes were expected in this indicator because it is not covered by the solution. The second criterion is the one we should focus, for instance, 20% of the technologies responded as neutral for ‘phosphorus’. However, it is expected that some of them could provide recovery of phosphorus, although it is not the focus of the technology, for instance, in technologies RL5.LL47 and RL13.LL10. Therefore, some of the technologies could be used in the same system aiming to improve positive results in the agricultural system.

‘Unknown’ responses are the most worrying concern, although, we understand some indicators will depend strongly on local conditions (i.e., soil, climate) and management operations (i.e., application of organic fertilizers). Therefore, ‘unknown’ is the best response for the indicator. On the other hand, the response ‘unknown’ may changes to ‘positive’, ‘negative’ or ‘neutral’ under these specific conditions after full assessments using LCA.



Legend: RP = Rock phosphate; NG = Natural Gas; OI = Oil; EN = Energy; WT = Water; SQ = Soil Quality; NR = Nutrients recovered; AM = Ammonia (air); N2O = Nitrous oxide (air); CH4 = Methane (air); NO3 = Nitrate (water); P = Phosphorus; PM = Particulate matter; CFP = Carbon Footprint; SOM = Effective Soil Organic Matter; REP = Renewable energy production. RL.1 = Innovative solutions for optimized nutrient & GHG in animal husbandry; RL.2 = Innovative soil, fertilization & crop management systems & practices; RL.3 = Tools, techniques & systems for higher-precision fertilization; RL.4 = Biobased fertilisers (N, P) and soil enhancers (OC) from agro-residues; and RL.5 = Novel animal feeds produced from agro-residues

Figure 10. Dashboard indicators responses grouped by research line

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4.2.1. Research line 1 'Innovative solutions for optimized nutrient & GHG in animal husbandry'

Technologies in research line 1 'Innovative solutions for optimized nutrient & GHG in animal husbandry' can mostly contribute to positive impacts in the indicators 'Nutrients recovered' (100%), reduction of 'ammonia' emissions (90%) and 'carbon footprint' (90%). Regarding negative impacts, 'energy' (40%) is the indicator more negatively impacted. On the other hand, the indicators 'natural gas' (80%), 'oil' (70%), 'rock phosphate' (60%), 'water' (60%) are the most unimpacted by this set of technologies, and further investigation is necessary in the indicator 'particulate matter', being the most unknown indicator (70%).

Regarding the Index of Qualitative Variation (IQV) for this research line, higher IQVs (IQV > 0.75) were calculated for 'nitrate' (IQV = 0.88), 'phosphorus' (IQV = 0.88), 'soil quality' (IQV = 0.77), 'methane' (IQV = 0.77), 'rock phosphate' (IQV = 0.75) and 'water' (IQV = 0.75). Therefore, for those indicators, we cannot assume a typical response from the technologies for the indicator. On the other hand, a typical impact (positive) from technologies in RL.1 can be expected in 'nutrients recovered' (IQV = 0), 'ammonia' and 'carbon footprint' (IQV = 0.24).

4.2.2 Research line 2 'Innovative soil, fertilization & crop management systems & practices'

Technologies in research line 2 'Innovative soil, fertilization & crop management systems & practices' will contribute significantly with the reduction of rock phosphate use (100%), increasing 'soil quality' (100%) and 'nutrients recovered' (100%) and reduction of 'carbon footprint' (100%). Negative impacts come from increasing 'nitrous oxide' emissions (75%), 'ammonia' volatilization (50%), 'particulate matter' formation (50%) and 'oil' consumption. 'Water' (75%) consumption is not (or significantly) impacted by the technologies in RL. 2, and more investigation is required for 'ammonia' (50%) and 'methane' (50%) indicators to better describe all technologies in this RL.

In relation to the IQV, typical positive impact from the technologies can be assumed for the indicators (all with IQV = 0) 'rock phosphate', 'soil quality', 'nutrients recovered' and 'carbon footprint'. In opposition, not typical impacts can be assumed for 'oil', 'non-renewable energy consumption', 'methane', 'nitrates', 'particulate matter' and 'renewable energy production' (IQV = 0.83).

4.2.3 Research line 3 'Tools, techniques & systems for higher-precision fertilization'

Technologies in research line 3 'Tools, techniques & systems for higher-precision fertilization' will have a positive impact in the indicators 'nutrient recovered' (100%), 'carbon footprint' (100%) and reducing 'nitrate' (100%) and 'phosphorus' leaching (83%). Negative impacts can come from the technologies in 'ammonia' volatilization (17%) and 'nitrous oxide' (17%) emissions. No impact will be caused to 'energy', and 83% of the experts responded as 'neutral' regarding impacts on 'oil', 'water' and 'renewable energy production'. As in RL.2 'particulate matter' needs further investigation, being the most unknown (67%) indicator in the RL.

In RL.3, positive typical impacts can be assumed for 'nutrients recovered' (IQV = 100) and 'carbon footprint' (IQV = 100). 'Non-renewable energy consumption' has a IQV equal to zero for neutral

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impact. That said, for the indicators 'soil quality' (IQV = 0.81), 'methane' (IQV = 0.84) and 'nitrous oxide' (IQV = 0.96) not typical impact can be expected from the technologies.

4.2.4 Research line 4 'Biobased fertilisers (N, P) and soil enhancers (OC) from agro-residues'

Technologies in research line 4 'Biobased fertilisers (N, P) and soil enhancers (OC) from agro-residues' will provide positive impacts in 'nutrients recovered' (100%), 'carbon footprint' (89%), 'natural gas' (89%) and 'rock phosphate' (83%). On the other hand, there might be an increasing of energy consumption in 33% of the technologies. 'Oil' is the indicator most unimpacted (89%), and 'particulate matter' requires more investigation since 67% responded as unknown for the potential impacts caused.

Regarding results in RL.4, a IQV of zero was obtained for 'nutrients recovered', and it is the only indicator we can expect a typical response (positive) from the technologies. In opposition, for following indicators is not possible to predict the impact from the technologies: 'nitrous oxide' (IQV = 0.93), 'ammonia' (IQV = 0.92), 'phosphorus', and 'nitrate' (IQV = 0.88).

4.2.5 Research line 5 'Novel animal feeds produced from agro-residues'

Finally, technologies in research line 5 'Novel animal feeds produced from agro-residues' will contribute mostly with 'Nutrients recovered' (100%), 'nitrate' and 'phosphorus' leaching (100%), and 'soil quality' (83%). 'Energy' and 'water' consumption can increase in 33% and 33% of the technologies, adding negative impacts to the system. Technologies in RL.5 has no (or no significant) impact especially in the indicators 'methane', and 'renewable energy production'. Again, 'particulate matter' was the most unknown indicator with 83% of the responses.

In this research line, several indicators presented IQV lower than 0.25, therefore, we can say that potential positive impacts are expected for these indicators in this RL. IQV equal to zero was found for 'nutrients recovered', 'nitrates' and 'phosphorus'. On the other hand, for six indicators a typical impact cannot be expected due to the high variation between the technologies. IQV equal to 0.89 was found for 'rock phosphate', natural gas' and 'non-renewable energy consumption'; IQV equal to 0.81, for 'oil', 'non-renewable energy consumption' and 'nitrous oxide'.

4.2.6 Index of Qualitative Variation for the environmental screening using DBI

In Table 4, main contributions (positive and negative) for each research line, are highlighted.

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Table 4. Summary of main contributions (positive impacts) and potential red flags (negative impacts) provided by the technologies in Nutri2Cycle project.

Research Line	Examples of positive impacts	Examples of negative impacts
1: Innovative solutions for optimized nutrient & GHG in animal husbandry	• Microorganisms will conserve nitrogen in manure, avoiding ammonia volatilization. • Digestate can have positive effect on soil properties. • Reduction of N_2O and CH_4 emissions will contribute to reducing CFP.	• Pumping and mixing are necessary.
2: Innovative soil, fertilization & crop management systems & practices	• Combination of anaerobic digestion and minimum tillage can bring significant energy savings. • The combined use of bio-based products with conventional chemical fertiliser would increase nutrients being recycled closing the C, N and P loop in the agro-ecosystem.	• One critical point on the use of digestate is the risk of gaseous emissions during spreading and possible nitrate leaching to groundwater.
3: Tools, techniques & systems for higher-precision fertilization	• The nutrient use efficiency of organic fertilisers and reduce the use of mineral N and P fertiliser Reduction of carbon footprint. • The innovation enhances fertilization optimisation by minimizing over- or under-fertilisation, reducing the carbon footprint. •	• Slurry injection substantially reduces NH3 emissions, but it increases N2O emissions compared to broadcast application.
4: Biobased fertilisers (N, P) and soil enhancers (OC) from agro-residues	• Since digestate contains nitrogen and phosphorus, reduction in the use of rock phosphate and natural gas can be expected to a certain extent reducing carbon footprint. • The partly or fully substitution of synthetic fertilisers by this concentrate can help reduce the consumption of rock phosphate and natural gas.	• There will be an increase of ammonia emissions as a consequence of manure application. • Production of ammonium nitrate via stripping/scrubbing technology requires electricity.
5: Novel animal feeds produced from agro-residues	• Processing livestock manure with insects will recover nutrients such as nitrogen, phosphate, potassium and several other minerals. • Reduction of water consumption due to crop varieties adaptation to different agrosystems and agricultural practices.	• An insect facility will also consume primary resources such as natural gas, oil, electricity and water. • The electricity requirement is high during digestate pre-treatment, operation of closed bioreactors, and harvesting systems.

When we calculated the IQV for the 44 technologies, for only two indicators a typical impact (in this case positive) can be expected, 'nutrients recovered' and 'carbon footprint (Figure 11). Thus, we can see the importance of separating these technologies by research line, because, although they have the same goal, nutrient recovery or recycling, they follow different approaches to achieve this goal.

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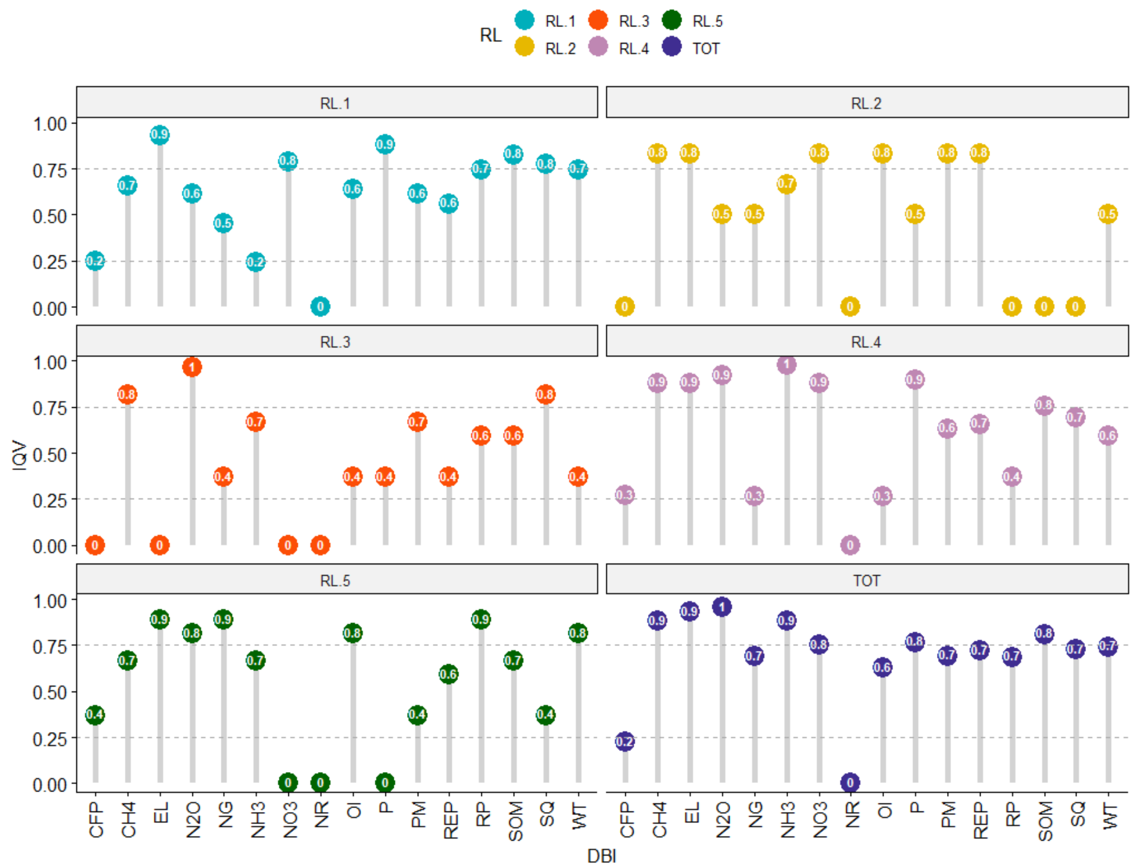

Legend: RP = Rock phosphate; NG = Natural Gas; OI = Oil; EN = Energy; WT = Water; SQ = Soil Quality; NR = Nutrients recovered; AM = Ammonia (air); N2O = Nitrous oxide (air); CH4 = Methane (air); NO3 = Nitrate (water); P = Phosphorus; PM = Particulate matter; CFP = Carbon Footprint; SOM = Effective Soil Organic Matter; REP = Renewable energy production. RL.1 = Innovative solutions for optimized nutrient & GHG in animal husbandry; RL.2 = Innovative soil, fertilization & crop management systems & practices; RL.3 = Tools, techniques & systems for higher-precision fertilization; RL.4 = Biobased fertilisers (N, P) and soil enhancers (OC) from agro-residues; and RL.5 = Novel animal feeds produced from agro-residues.

Figure 11. Index of Qualitative Variation (IQV) by research line and considering the 44 technologies in Nutri2Cycle. Note: IQV <0.25 = low variation; IQV> 0.75 High variation

4.3. Potential trade-offs in the agricultural systems

The DBI can also show potential trade-offs with the insertion of the novel technologies in the agricultural systems.

In Figure 12, we show positive and negatives effects expected of the technologies in RL1., to better check potential trade-offs. In 50% of the technologies is possible to see that potential trade-offs can happen, especially related to the increasing of 'non-renewable energy consumption', but for only one the technology (RL17.LL18), the increasing cannot be compensated by the production of renewable energy production. Potential trade-offs in RL17.LL19 for methane emissions can occur since the biomass substrate added could risk increasing CH_4 formation, despite there is a considerable reduction of ammonia emissions (Prado et al. 2020). Regarding the contribution to decrease soil quality in RL17.LL18, it is the fact that acidified slurry can potentially lower the pH of the soil to levels below the optimum for plant development. However, this can be controlled, for instance, the Danish agricultural advisory and research o29rganization SEGES recommends to apply an equivalent of 75 kg of

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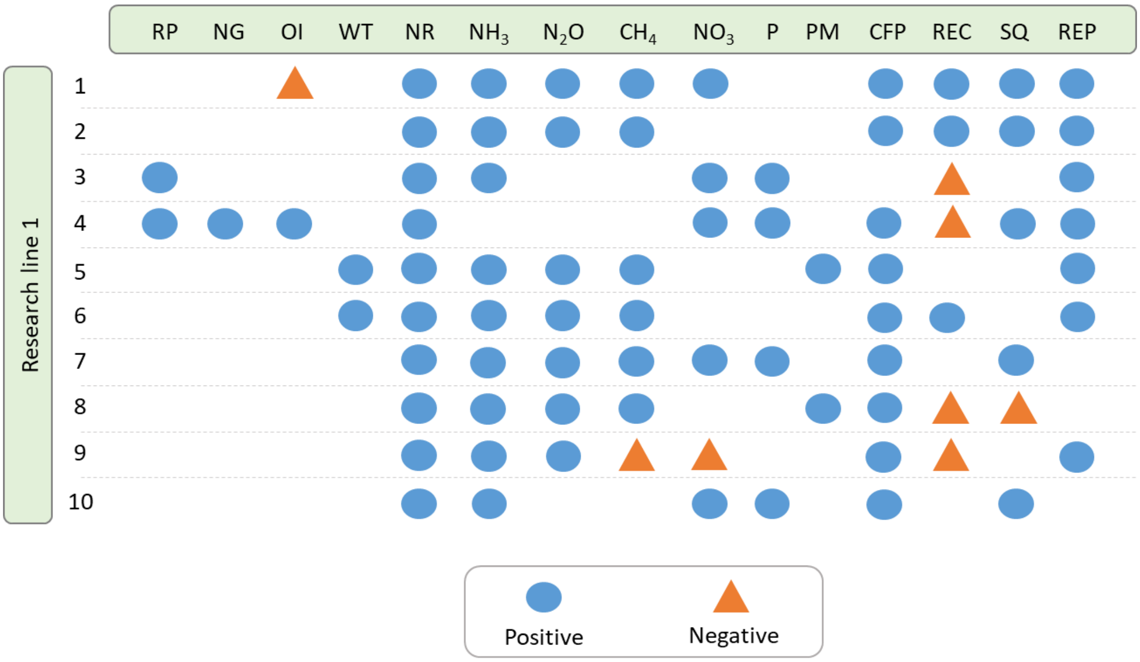
agricultural lime (75% CaCO3) per hectare and year, if the manure is acidified with 1 L of sulphuric acid per ton and applied at a rate of 30 t/ha (SEGES 2014).



Legend: RP = Rock phosphate; NG = Natural Gas; OI = Oil; EN = Energy; WT = Water; SQ = Soil Quality; NR = Nutrients recovered; AM = Ammonia (air); N2O = Nitrous oxide (air); CH4 = Methane (air); NO3 = Nitrate (water); P = Phosphorus; PM = Particulate matter; CFP = Carbon Footprint; SOM = Effective Soil Organic Matter; REP = Renewable energy production. 1 = RL13.LL10; 2 = RL13.LL48; 3 = RL14.LL61; 4 = RL15.LL8; 5 = RL15.LL11; 6 = RL15.LL24; 7 = RL16.LL27; 8 = RL17.LL18; 9 = RL17.LL19; 10 = RL18.LL32.

Figure 12. Potential trade-offs in RL.1 'Innovative solutions for optimized nutrient & GHG in animal husbandry'

The potential trade-offs in RL.2, focused on the use of organic fertilizers are related especially to the increasing of N_2O and NH_3 (consequently PM) emissions (Figure 13). However, these trade-offs can be reduced through the different organic fertilisers application, for instance, through sub-surface injection of digestate. The increased oil consumption is related to the increased use of machineries on the field, and crop residues are directly incorporated in the soil in RL1.LL71, the carbon is no longer available for bioenergy. In addition, it is expected some leakage of nitrate to recipient waters due to the application of cattle slurry, poultry manure.

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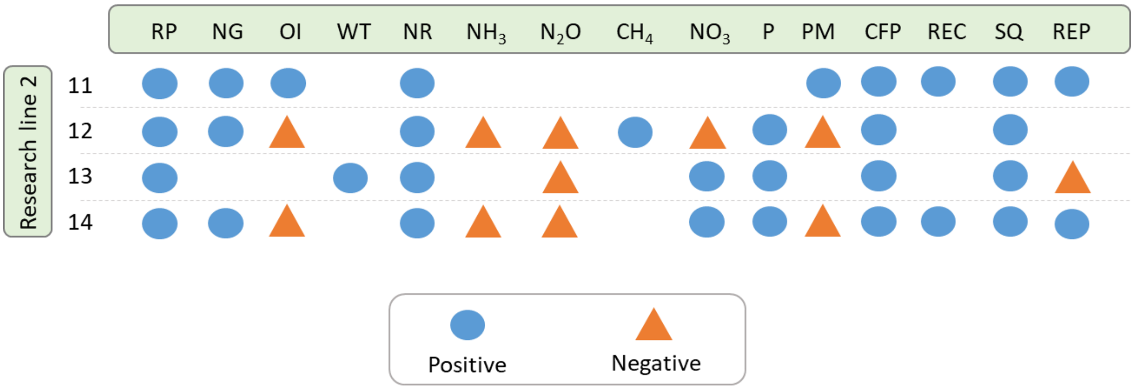
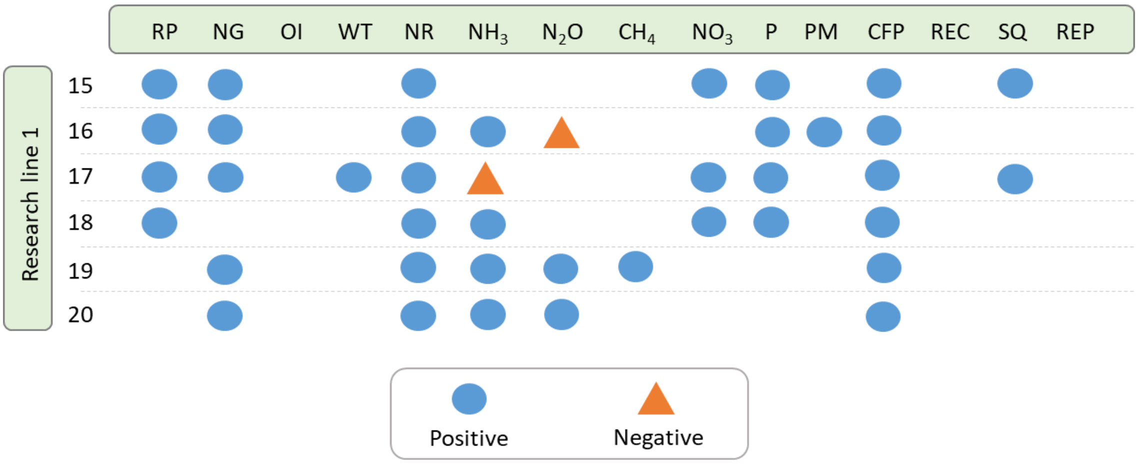


Legend: RP = Rock phosphate; NG = Natural Gas; OI = Oil; EN = Energy; WT = Water; SQ = Soil Quality; NR = Nutrients recovered; AM = Ammonia (air); N2O = Nitrous oxide (air); CH4 = Methane (air); NO3 = Nitrate (water); P = Phosphorus; PM = Particulate matter; CFP = Carbon Footprint; SOM = Effective Soil Organic Matter; REP = Renewable energy production. 11 = RL1.LL16; 12 = RL1.LL17; 13 = RL1.LL71; 14 = RL2.LL21.

Figure 13. Potential trade-offs in RL.2 'Innovative soil, fertilisation & crop management systems & practices'

It is not expected many trade-offs, considering the DBI, in the technologies of RL. 3 (Figure 14). The trade-offs identified, valorisation of manure but increasing emissions, are related to the use of organic fertilizers, not due to the precision fertilization applied in technologies RL20.LL28 and RL20.LL63.



Legend: RP = Rock phosphate; NG = Natural Gas; OI = Oil; EN = Energy; WT = Water; SQ = Soil Quality; NR = Nutrients recovered; AM = Ammonia (air); N2O = Nitrous oxide (air); CH4 = Methane (air); NO3 = Nitrate (water); P = Phosphorus; PM = Particulate matter; CFP = Carbon Footprint; SOM = Effective Soil Organic Matter; REP = Renewable energy production. 15 = RL19.LL30; 16 = RL20.LL28; 17 = RL20.LL63; 18 = RL21.LL73.

Figure 14. Potential trade-offs in RL.3 'Tools, techniques & systems for higher-precision fertilization'

Similar as in RL.1 and RL.2, the main trade-offs expected with the inclusion of RL.4 technologies are related to NH_3 and N_2O emissions, and non-renewable energy consumption (Figure 15). On one hand, with technology RL3.LL66, rock phosphate and natural consumption are reduced since organic fertilizer is applied on the field. On the other hand, the effect of application of digestate on emissions to the environment, studies show that digestate increase N_2O and NH_3 emissions. In technology RL5.LL47, the valorisation of poultry manure and/or solid state digestate mixed

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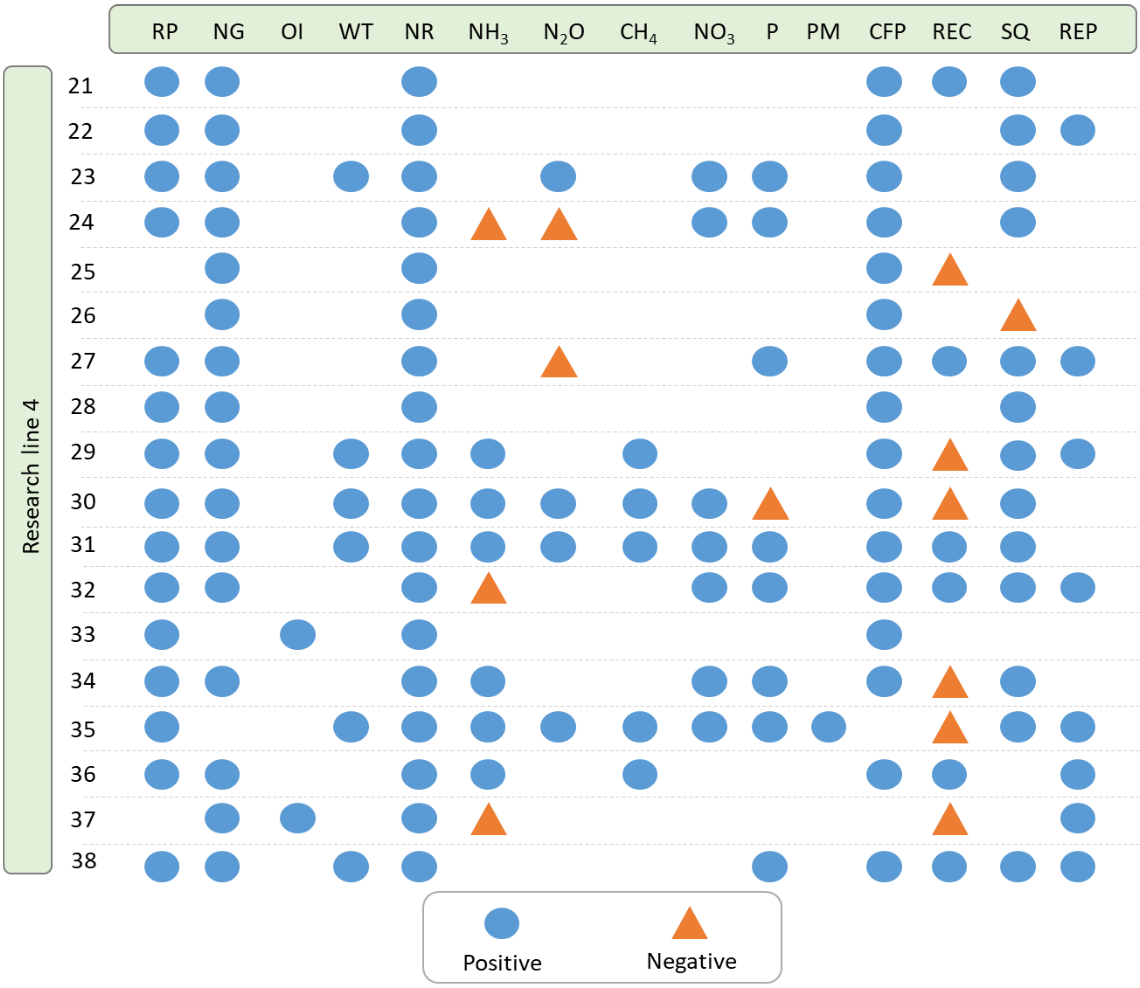
with bulking agents and biochars to grow substrates, helps to save rock phosphate and natural gas, but it requires energy input.



Legend: RP = Rock phosphate; NG = Natural Gas; OI = Oil; EN = Energy; WT = Water; SQ = Soil Quality; NR = Nutrients recovered; AM = Ammonia (air); N2O = Nitrous oxide (air); CH4 = Methane (air); NO3 = Nitrate (water); P = Phosphorus; PM = Particulate matter; CFP = Carbon Footprint; SOM = Effective Soil Organic Matter; REP = Renewable energy production. 21 = RL.3LL14; 22 = RL3.LL15; 23 = RL3.LL57; 24 = RL3.LL66; 25 = RL4.LL1; 26 = RL4.LL2; 27 = RL4.LL6; 28 = RL4.LL9; 29 = RL5.LL47; 30 = RL5.LL62; 31 = RL6.LL49; 32 = RL6.LL52; 33 = RL6.LL65; 34 = RL7.LL20; 35 = RL7.LL23; 36 = RL7.LL43; 37 = RL7.LL55; 38 = RL8.LL22.

Figure 15. Potential trade-offs in RL.4 'biobased fertilisers (N, P) and soil enhancers (OC) from agro-residues'

Finally, in RL5, the potential trade-offs that can occur in the systems due to the inclusion of the novel technologies are mainly linked to increased water and non-renewable energy consumption (Figure 16). Technology RL24, on one hand, aims to cultivate microalgae high value food and feed ingredient besides their high protein content, using digestate to lower costs with nutrients to the microalgae growth, making this product more economic attractive while recovering nutrients. On the other hand, besides the water to microalgae growth and non-renewable energy consumption during digestate pre-treatment, operation of closed bioreactors, and harvesting systems, it also requires additional phosphorus as few digestate sources may be poor in soluble P.

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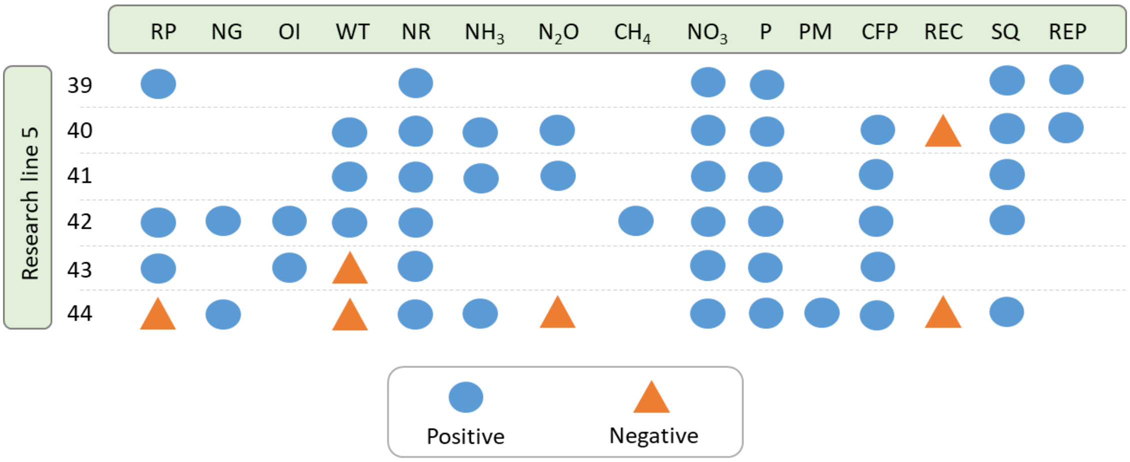

Legend: RP = Rock phosphate; NG = Natural Gas; OI = Oil; EN = Energy; WT = Water; SQ = Soil Quality; NR = Nutrients recovered; AM = Ammonia (air); N2O = Nitrous oxide (air); CH4 = Methane (air); NO3 = Nitrate (water); P = Phosphorus; PM = Particulate matter; CFP = Carbon Footprint; SOM = Effective Soil Organic Matter; REP = Renewable energy production. 39 = RL9.LL40; 40 = RL10.LL25; 41 = RL10.LL45; 42 = RL11.LL34; 43 = RL12.LL41; 44 = RL24.

Figure 16. Potential trade-offs in RL.5 'Novel animal feeds produced from agro-residues'

4.4. Validation of the qualitative results using literature data

Qualitative methods have been increasingly developed and applied in different fields as social risk (Dvorak et al. 2020), biology (Chidumayo et al. 2014), also environmental assessment (Toro et al. 2013). Validation represents a "confirmation by examination and provision of objective evidence that the particular requirements for a specified intended use are fulfilled" (ISO/IEC 2005). Validation performance of qualitative methods has still no consensus about validation protocol and the terminology used for qualitative methods, but for some time now, several authors have been used information available in the literature for the validation of results (López et al. 2015).

In the current work, literature data were used to validate the method Delphi and the scenario storylines created to assess the potential impacts of novel technologies for nutrient recovery in agriculture. The validation procedure is made by research line, highlighting literature data for similar scenarios for some technologies, indicators, and positive responses.

It is important to keep in mind that since technologies can vary significantly under different conditions in which they are applied, the values presented in the next sections should be applied as benchmarking values when the technologies are applied under the same conditions (i.e., climate and field operations management). In addition, it is not always possible to have numbers for all DBI since most of the studies focus only on a few indicators.

4.4.1 Validation for technologies in Research Line A 'Innovative solutions for optimized nutrient & GHG in animal husbandry'

Different studies showed improvement on emissions when treating slurry (RL17.LL18 and RL17.LL19), a reduction of NH_3 volatilization, 51-90% during slurry storage (Huang et al. 2006; Dai et al. 2013; Petersen et al. 2012), 50-70% with in-house acidification (Birkmose & Vestergaard 2012; Kai et al. 2008; Fangueiro et al. 2015; Monteny & Erisman 1998).

Park et al. (2018) suggested reductions of nitrate leaching and N_2O emissions during field application of acidified slurry, methane formation is lowered in Saufi et al. (2018) and Petersen et al. (2016). Energy consumption will be increased to treat slurry (De Vries et al 2012), and

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animal production increased due improvement in animal welfare promoted by the better quality in the animal rooms (Jensen 2002), as in technologies RL16.LL27, RL15.LL24, RL13.LL48 and RL17.LL18. When looking at the total GHG emissions due to anaerobic digestion, as in RL13.LL10, it can be concluded that up to 50% of the emissions can be reduced by applying this technique (Vergote et al. 2020).

Manure valorization applying direct separation of faecal and urine (RL15.LL24) recovers an N rich urine fraction and a P solid fraction (Fangueiro et al. 2008), reduces NH_3 emissions up to 75%, CH_4 emissions up to 80%, and odour emission up to 74%, when compared to conventional manure management systems (Aarnink et al. 2007; Lachance et al. 2005; De Vries et al. 2013).

The reduction of nitrate leaching in RL15.LL8 was attested in Cambardella and Elliott (1994) due to the binding capacity of soil to nitrates provided by carbon-rich soil enhancers. In addition, processing manure near livestock farms, and applying the bio-based fertilisers locally at arable farms will reduce the CFP (De Vries et al. 2012).

4.4.2 Validation for technologies in Research Line B 'Innovative soil, fertilisation & crop management systems & practices'

Anaerobic digestion (RL1.LL16) and minimum tillage (RL1.LL16 and RL1.LL71) can greatly reduce, natural gas consumption due to the production of gas and the nitrogen-based fertilizer digestate (Smith 2002), oil consumption since tillage-related operations are energy-intensive (Koga et al. 2003) and CFP due to lower fuel requirements (Gan et al. 2011). Soil quality can be increased in technologies RL1.LL16, RL1.LL71 and RL1.LL17 due to, respectively, minimum tillage techniques (Tambone et al. 2009), balanced use of organic-inorganic fertilizers (Geng et al. 2019.)

Different techniques of organic fertilizers application (RL1.LL16 and RL1.LL17), like the injection of digestate, can reduce ammonia emissions to levels similar to chemical fertilization (Riva et al. 2016). In addition, nitrate leaching is reduced by applying organic fertilizers and introducing catch crops (RL1.LL16 and RL2.LL21) (Zilio et al. 2020; Montemayor et al. 2019).

Previous studies have shown no significant differences between crop yields obtained with digestate fertilization (RL1.LL16) and those obtainable by the use of urea (Riva et al. 2016). However, the combined application of chemical and organic sources (RL1.LL17 and RL2.LL21) is widely recognized as a way of sustainably increasing crop productivity (Baghdadi et al. 2018; Montemayor et al. 2019).

4.4.3 Validation for technologies in Research Line C 'Tools, techniques & systems for higher-precision fertilization'

The use of N sensors (RL19.LL30 and RL23.LL13) and precision fertilization using organic materials (RL20.LL28, RL20.LL63, RL21.LL73, RL22.LL68) has shown good results in terms of productivity and reducing N and P losses to the ground -and surface water (Stamatiadis et al. 2018; Banger et al. 2010; Forrestal et al. 2012; Pajares 2011; Aquino-Santos et al. 2011).

The application of organic fertiliser helps (RL20.LL28 and RL20.LL63) to sequester carbon in the soil (Banger et al. 2010) and close the C cycle. Especially in the long term, the effective soil organic matter (SOM) will increase (Meng et al. 2005).

Replacing mineral fertilisers with organic fertilisers and minimizing over- or under-fertilisation and precision fertilisation will reduce the CFP (Liu et al. 2016; Dell et al. 2011).

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A significant reduction in ammonia emission can be promoted when pig manure processing reduces the manure storage time (RL21.LL73), and CO_2 emissions (and CFP) can be reduced when the bio-based fertilizers are applied locally at arable farms (Hilhorst et al. 2002).

4.4.4 Validation for technologies in Research Line D 'Biobased fertilisers (N, P) and soil enhancers (OC) from agro-residues'

The application of digestates (RL3.LL66) showed that the continuous application of digestate increased by 0.5% the content of soil organic matter (SOM) content in seven years, and has a positive effect on soil fertility increasing soil organic carbon (Bezzi et al. 2016; Möller and Müller 2012). The application of manure (RL3.LL57; RL3.LL14) will increase the total N and available P (Adeleye et al., 2010), thus enhancing soil health and fertility.

Organic fertilizers as manure (RL3.LL57; RL3.LL14; RL3.LL15; RL7.LL55) reduce the need for irrigation, due to the increase of soil water holding capacity (Haynes and Naidu, 1998; Adeleye et al. 2010), and improve soil quality by adding carbon and nitrogen (Meng et al. 2005). At the same time, there is a small risk of phosphorus leaching due to organic P mineralization and low P mobility (Kang et al. 2011), and nitrate leaching due to the slow mineralization of nitrogen from manure (Nyamangara et al., 2003). Manure application (RL3.LL57) will contribute also to the reduction of N_2O emissions compared to mineral fertilizers (Ball et al. 2004), to reduce CFP by adding a material rich in carbon that will contribute to close the C cycle (Cerutii et al. 2010), and to increase crop yields (Steiner et al. 2007; Adeleye et al. 2010).

The treatment applied to the manure (RL5.LL62; RL7.LL55) can reduce NH_3 emissions relative to raw manure, GHG emissions (Loyon et al. 2007; Dennehy et al. 2017; Prado et al. 2020) and nitrate leaching (Cameira et al. 2019). Adding a material rich in carbon to the soil will contribute to close the C cycle, reducing the CFP associated with the use of mineral fertilisers (Krause & Rotter 2018), and will help to restore SOM and increase soil health (FAO 2019). Processing pig manure by vacuum stripping (RL7.LL20), is expected an increase soil quality because of the addition of organic matter (Yagüe et al. 2016) and the valorization of manure as fertilizer means a recovering of nutrients (Tao et al. 2018).

The pig manure refinery (RL7.LL23) helps to save water by separating clean water from the effluent (Ledda, Salati & Adani 2013; Utomo, Zhi & Jun 2017; Cath et al. 2005). Avoiding stocking swine livestock effluent by treating it immediately can greatly reduce emissions of GHG and NH_3 (Husted 1994). The pig manure evaporation plant (RL7.LL43) produces green Energy, and compared to mono-digestion, co-digestion produces more bio-energy (Thyø & Wenzel 2007; De Vries et al. 2012). According to Melse and Ogink (2005), 40 to 100% is the expected reduction in NH_3 emission using an ammonia scrubber (RL7.LL43).

RL4.LL1 and RL4.LL2 recover ammonium nitrate and calcium ammonium nitrate to be used as N fertilizers, having the same effect on yield when using synthetic N fertilizer, but saving natural gas consumption (Sigurnjak et al. 2019).

Tambone et al. (2019) state that liquid fraction (LF) of digestate (RL4.LL9) contains a large amount of organic carbon that is biologically stable, and as such can act as organic amendment contributing to soil organic carbon balance, consequently, to soil quality improvement. Using biochar in composting poultry manure (RL5.LL47) allows reduction of ammonia emission during composting (Janczak et al. 2017).

Struvites (RL6.LL65; RL6.LL49; RL6.LL52) have proved to be highly pure fertilizers, having even fewer or no contaminants than the commonly used phosphorus fertilizers processed from P rock (Britton 2007; Huygens et al. 2018). According to Bradford-Hartke et al. (2015), recovering P

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using struvite precipitation resulted in positive environmental impacts due to energy and chemical use savings and avoided fertilizer production. Depending on the technology used, up to 40% of N and 90% of P can be recovered from the effluent (Val del Río et al. 2016). As stated by Britton et al. (2007), the struvite production from digestate results in reductions of over 50% in CO_2 and N_2O oxide emissions and 80% lower GHG emissions on a carbon dioxide equivalent (CO2eq) basis than traditional fertilizer manufacture. In addition, Zhang & Lau (2008) claimed that struvite production can reduce this emission by 84% maximum, consequently reducing particulate matter formation (Behera & Sharma 2010; Sharma et al. 2007).

Finally, the BioPhosphate product (RL8.LL22) has concentrated >30% phosphorus pentoxide (P_2O_5), making it a high-quality innovative fertilizer (Someus & Pugliese 2018). In addition, bone biochar showed potential for soil amendment, improving soil quality (Siebers et al. 2013). Also, using a zero-emission autothermal carbonization system, called 3R, the technology contributes to reducing CFP (Someus 2009).

4.4.5 Validation for technologies in Research Line E 'Novel animal feeds produced from agro-residues'

Processing livestock manure with insects (RL9.LL40) will recover nutrients such as nitrogen (~38%), phosphate (~28%), potassium (~14%), and several other minerals, varying with the substrate (Parodi et al. 2020).

Cultivation of soybeans (RL10.LL25) is reported to increase soil quality (Gao et al. 2017; Simioni et al. 2016). No-till management in some soil types and climatic conditions could contribute to reducing net GHG emissions (Ogle et al. 2019). Extruded soybean was also characterized by the highest energy value compared to other processed forms of soybean (Wenda-Piesik & Doroszewski 2018/2019).

Legumes (RL10.LL45) are capable of fixing atmospheric nitrogen, improve soil structure, break cycles of diseases and pests, improving biodiversity and CO_2 capture, and reducing N_2O emission, which are of great interest for animal feed (Staginari et al. 2017). According to Ma et al. (2018), 25% of the yield-scaled N_2O-N emission would be saved by switching to a legume rotation under climate change conditions.

When natural grass is harvested for animal feed (RL11.LL34) instead of locally composted in situ, farmers need 25% less hay production which results in a saving of emissions.

Finally, in a recent study by Mohedano et al. (2019), it was shown that duckweed ponds (RL12.LL41) have a net carbon capture of at least three times more CO_2 than it emits, at low carbon loading ranges, contributing to reduce CFP compared to the reference scenario.

4.5 Infographic to present the dashboard indicators for easy-to-use communication

Infographics should be capable of simplifying a complex subject, at the same keeping the attention of readers using attractive elements. The idea of using this infographic in the form of dashboard indicators in Nutri2Cycle, such as the one presented in Figure 17, is that end-users could have the information in a more user-friendly approach, instead of reading the whole report containing the same content as the Figure. In addition, visuals help end-users and other stakeholders process the content more efficiently, focusing on several aspects and be able to compare all of them in the same framework. In this deliverable we have therefore developed this example of an infographic that we will use to present the technology to farmers, policymakers, etc.

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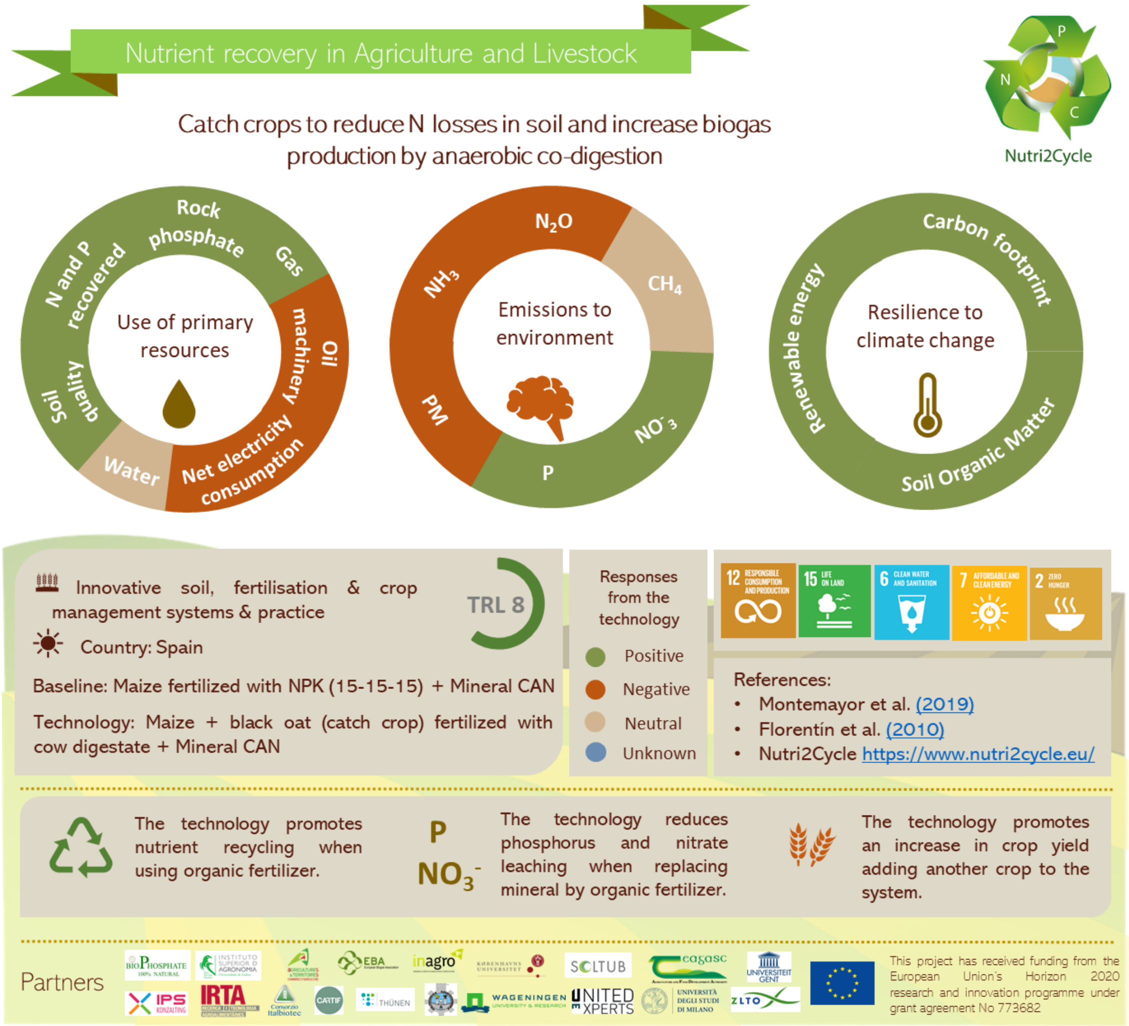

Figure 17. Infographic focusing easy-to-use approach towards policy makers and end-users using as example technology RL2.LL21

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5 Conclusions

The current deliverable presents a first approach to score Nutri2Cycle technologies for their environmental impact. The score has been provided by considering a series of qualitative dashboard indicators defined in the project.

The current work allowed summarising how much the different technologies could potentially contribute to reducing negative environmental consequences. We can highlight that they are mainly contributing to recovery of nutrients, reduction of climate change and improving 'soil quality'. Research Lines 3 and 5 have a high number of technologies contributing to reducing N and P leaching. Also, natural resources 'rock phosphate' and 'natural gas' will be saved when technologies of Research Lines 2, 3 and 4 will be applied.

Dashboard indicators applied in the current deliverable allow a simplified assessment of all technologies. Moreover, the survey conducted among the different Nutri2Cycle partners and developers of shortlisted technologies allow us to prioritize which relevant indicators to be considered when further developing the technologies in relation to nutrient recovery. In the next phase of the project (WP3), a subset of these shortlisted technologies will be analysed using Life Cycle Assessment (LCA) tools to evaluate their environmental performances in much more detail. This means that the qualitative results obtained in this deliverable can be compared with the more comprehensive and quantitative results obtained with the LCA and allow their validation or suggest corrections.

In addition, following the suggestions in D1.1, also social and economic criteria will be evaluated and reported (Deliverable D3.3 and D3.4) and finally Multicriteria (Deliverable D2.6) will be applied. Based on results of indicators tested for each technology Nutri2Cycle will provide a selection of indicators feasible and useful to judge/score improvement of potential technologies.

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Annex A - Description of technologies responses for the qualitative assessment in Nutri2Cycle project

Research line 1. Innovative solutions for optimized nutrient & GHG in animal husbandry

RL17.LL19 Slurry bio-acidification using organic waste products to reduce NH3 volatilisation and increase fertiliser value

BRIEF DESCRIPTION TECHNOLOGY: Bio-acidification aims to reduce ammonia emissions to the atmosphere from the animal Slurry management, similar to Slurry acidification using sulphuric acid, but without using industrial, synthetic acids. Bio-acidification is based on decreasing the pH through natural fermentation in the manure. Of particular relevance for organic farms and for bio-acidified Slurry as feedstock in AD.

This alternative is relevant because:

- Although sulphuric acid is one of the cheapest industrial acids, it is still a cost

- Organic farms under current EU and national organic certification schemes are not allowed to use synthetic acids, and these farms also need to reduce their ammonia emissions and increase manure fertiliser value and

- Acidification with sulphuric acid increases the sulphur content to a level, which prohibits extensive use of acidified Slurry in anaerobic digestion biogas plants, due to the inhibition of the biogas process.

- Concentrated sulphuric acid is a hazardous and corrosive chemical and may cause excessive foaming when added to Slurry.

- By lowering the pH of the Slurry with sulphuric acid the equilibrium between ammonia (NH3) and ammonium (NH4+) shift towards NH4+. Ammonium is the dissolved form of inorganic N in the Slurry and does not volatilise to the atmosphere, but stays in the Slurry.

- Bio-acidification is based on stimulating the formation of organic acids (especially lactic and acetic acid) in the manure by fermentation. This can be done by adding simple sugars or other carbohydrates that easily hydrolyse into sugars. Those promote lactic acid fermentation and a rapid pH drop, preventing methane formation.

REFERENCE AGAINST WILL BE AVALUATED: The reference will be pig/cattle Slurry management without acidification in Denmark, the Netherlands and Spain; assuming Slurry pits beneath RLatted floors, weekly emptying of pits into a Slurry storage tank, and field application in the spring to growing crops (e.g. winter wheat). Storage and application requirements may vary depending on national legiRLation.

Expected effect in relation to the reference scenario:

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1. Use of Primary Resources

Rock Phosphate: Unimpacted.

Natural Gas: Unimpacted.

Oil: Unimpacted.

Water: Unimpacted.

Nutrients recovered: The ammonia retained in the Slurry is converted to plant available N. Given that acidification decreases the amount of N lost to the atmosphere, the nitrogen density of the Slurry is relatively higher and hence should potentially provide significantly more available N for the crop. However, the addition of an organic fermentation substrate may also enhance N immobilisation upon field application, though this effect is expected to be limited.

2. Emissions to the environment

Ammonia (air): NH3 emission reductions are the main objective of the technology. However, only few studies exists on that matter and reduction levels remain to be investigated. One study showed a reduction in NH3 volatilisation of 35-92% during storage (Huang et al 2006). Another study measured NH3 emissions during field application of untreated and bio-acidified Slurry and found that 26% and 5% of applied ammonia got emitted, respectively (Clemens et al 2002).

Nitrous oxide (air): The effect of bio-acidification on N2O emissions remains to be studied. However, studies on Slurry acidified with industrial acids would suggest reductions during field application (Park et al 2018).

Methane (air): Studies have shown that methane formation can be lowered due to bio-acidification (Bastami et al 2018). However, it is still unknown, whether the biomass substrate added could risk increasing CH4 formation, if pH is not sufficiently lowered.

Nitrates (water): Whether nitrate leaching rates change, mainly depends on whether the additional N in the Slurry is viewed as mineral fertiliser substitute or as a mean to apply more N to the field overall. In the latter case, this technology would have no effect on overall nitrate leaching.

Phosphorus (water): Unimpacted.

Particulate matter: Given the decreased emissions of ammonia, also particulate matter formation is lowered. However, direct particulate matter formation is not impacted.

3. Resilience to climate change

Carbon footprint: Probably reductions in N2O emissions, but unknown risk of CH4 emission.

Non-renewable energy consumption: In order to mix the Slurry with the acidifying agent, pumping and mixing are necessary. Due to the lack of pilot scale experiments and data, and it is not known as of today how much energy will be needed for this process. Outdoor storage acidification using industrial acids requires about 1.2 kWh/t of Slurry. Given that the volumetric ratio between the fermentation substrate to acidify and the Slurry is higher in bio-acidification, it can be assumed that energy consumption is higher than for regular sulphuric acid addition.

Soil quality: Unimpacted.

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Renewable energy production: If the acidified Slurry is fed into an anaerobic digestion plant instead of being directly land applied, the usage of residual or waste biomass as substrate can increase the Slurry's biogas potential and thus substitute other energy sources. However, in case the 'waste' stream is diverted from an alternative utilisation, competition might arise and best practise would have to be evaluated on a case-by-case basis.

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RL16.LL27 Use of an inoculate of microbiota and enzymatic pre-cursors to reduce ammonia emissions and optimize nutrient use efficiency in poultry manure

BRIEF DESCRIPTION TECHNOLOGY: Effective microorganisms (EM) are mixed cultures of beneficial naturally-occurring organisms that can be applied as inoculants to increase the microbial diversity of an ecosystem. The concept of EM was developed in the 1980s (Higa, 1991). EM contains selected species of microorganisms including predominant populations of lactic acid bacteria and yeasts, photosynthetic bacteria and other types of organisms. All of these are mutually compatible with one another and can coexist in liquid culture.

The traditional logic behind effective microorganism is based on a media inoculation with mixed cultures of beneficial microorganisms to create a more favourable environment for plant growth and health when the media is the soil. Olle and Willians (2013), studied the effect of EM when applied to soil on growth, yield, quality, and protection of vegetables, stated that 70% of published studies on this issue concluded that EM had a positive effect on growth of plants. The same authors concluded in another paper (Olle and Willians, 2015) that EM interact with the soil-plant ecosystem to suppress plant pathogens and agents of disease, to solubilise minerals, to conserve energy, to maintain the microbial-ecological balance of the soil, to increase photosynthetic efficiency, and to fix biological nitrogen.

Following this rationale, other research works have been focused on studying the effect of EM when they are included in animal diets. Ballena (2011), in a study with laying hens, concluded that the application of EM in feeds improved production and economic parameters in hen farms, becoming a viable alternative in poultry production.

The purpose of this work in Nutri2Cycle is to go one step further in the study of potential uses for EM and evaluate the influence of EM on the biostabilization of manure before its use as a fertilizer. The biostabilized manure, when applied to the soil, it is expected that progressively

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inhibit the attack of other bacteria and microorganisms that cause pathologies by having a colonizing effect on the ground due to the displacement produced by the space they occupy and by reducing their power supply.

The aim of the lactic bacteria is to transform part of the carbohydrates into lactic acid with a resulting effect that is the lowering of the pH with great control of pathogenic microorganisms. Phototrophic bacteria carry out incomplete anaerobic photosynthesis, being very useful because they will be capable of detoxifying the manure of toxic substances for the plant that are formed during fermentation.

REFERENCE AGAINST WILL BE AVALUATED: Conventional manure application without biostabilization of manure before its use as a fertilizer.

Effect in relation to the reference scenario:

1. Use of Primary Resources

Rock phosphate, Natural gas, Oil, Water: These indicators are not expected to change compared to the baseline.

Nutrients recovered: The action of EM allows to conserve nitrogen in the manure during the transformation process avoiding the loss of N as NH3. This N, together with the P present in the manure, can be later consumed by the plant promoting nutrients recycling.

2. Emissions to the environment

Ammonia (air): The action of EM allows to conserve nitrogen in the manure during the transformation process avoiding the loss of N as NH3.

Methane (air): They are also able to conserve nitrogen and carbon during the transformation of the manure avoiding the release of NH3 and CH4 gases.

Nitrous oxide (air): The use of EM helps to reduce GHG emissions to the atmosphere.

Nitrates (water) and Phosphorus (water): It is expected that 60-80 % of the N contained in the manure will be fixed by the microbial product and will not be lost as ammonia. In addition, the N will be in a form available to the plant. On the other, due to the action of the microbial product in the manure, the phosphorus contained in the manure will be kept in an assimilable form and will be prevented from binding to Ca, which would lead to a decrease in the availability of phosphorus. In short, due to the fixation of N and P in the manure by the action of micro-organisms, the nutrients will be in a better form available for the crop, thus, they will be released in a gradual way, avoiding their leaching and the pollution of water bodies.

Particulate matter: The indicator is not assessed by the technology.

3. Resilience to climate change

Carbon footprint: The use of EM helps to reduce GHG emissions to the atmosphere, thus reducing carbon footprint of the manure management and fertilization process.

Soil quality: The selected microorganisms constitute the growth environment of the plants with a great rooting and biostimulant effect, directly affecting the quality of the crops and the soil.

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Non-renewable energy consumption and Renewable energy production: The indicators are not affected by the technology.

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RL17.LL18 Slurry acidification with industrial acids to reduce NH3 volatilisation from animal husbandry - effects on multiple emissions and C, N and P dynamics in crop systems.

BRIEF DESCRIPTION TECHNOLOGY: By lowering the pH of the Slurry with sulphuric acid the equilibrium between ammonia (NH3) and ammonium (NH4+) shift towards NH4+. Ammonium is the dissolved form of inorganic N in the Slurry and does not volatilise to the atmosphere, but stays in the Slurry. This reduces ammonia emissions to the atmosphere (by >90%) from the entire animal Slurry management chain, i.e. the animal house, the storage tank and/or during the field application of slurries. As a co-benefit, acidification also reduces emissions of methane (CH4) and nitrous oxide (N2O), both potent greenhouse gases, from animal houses and Slurry storage facilities. Furthermore, this technology enables increased crop fertiliser nitrogen efficiency and may potentially enhance availability of several other nutrients (fertiliser, manure or soil derived). The technology is commercially available on the market (TRL 9) but currently applied mainly in the Scandinavian countries, especially Denmark, where up to 20% of all Slurry is acidified either in the animal house, the storage or during field application.

REFERENCE AGAINST WILL BE AVALUATED: The reference will be pig/cattle Slurry management without acidification in Denmark, the Netherlands and Spain; assuming Slurry pits beneath slatted floors, weekly emptying of pits into a Slurry storage tank, and field application in the spring to growing crops (e.g. winter wheat). Storage and application requirements may vary depending on national legislation.

Expected effect in relation to the reference scenario:

1. Use of Primary Resources

Rock Phosphate: No phosphorous is added, nor does the need for P application in the field alter because of slurry acidification. In order to acidify the slurry, phosphoric acid could be an option. However, it is rather uncommon also due to its relatively high costs compared to sulphuric acid.

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Oil: No information could be found regarding whether there is additional need for pumping energy and hence consumption of tractor diesel, to acidify the Slurry during field application. It is anyhow assumed to be negligible.

Nutrients recovered: The ammonia retained in the slurry is converted to plant available N. An experiment on acidified pig Slurry showed an increase of the mineral fertiliser (MF) equivalent value by up to 15-20%-points.7

Natural gas and Water: No changes are expected.

2. Emissions to the environment

Ammonia (air): In-house acidification reduces NH3 emissions from the animal house by 50-70% relative to untreated Slurry.7,10–13 Overall, studies on outdoor storage acidification of pig and cattle Slurry reported reduction potentials of 51-90% during storage.11,17,20 In field trials conducted in Denmark and Germany, cattle Slurry was acidified in the storage tank right before application. Ammonia emissions in the field were reduced by 42% and 79%, at pH 6.5 and pH 6.0, respectively.15 Other studies on both pig and cattle Slurry have shown that storage acidification to varying pH levels (pH 5.5-6.0) achieved reductions between 50 to 88%.7,16 Trials on in-field acidification have shown reductions of 40-80% in pig Slurry and 15-80% in cattle Slurry.11,12,17 Emission reductions achieved through Slurry acidification are comparable to those achieved by Slurry injection.6,18

Dinitrogen monoxide (air): In-house acidification seems to have no effect on in-house N2O emissions. 19 In-field acidification has shown to reduce gaseous emissions of N2O by 78%.16

Methane (air): In-house acidification slightly decreases methane emissions in the animal house. 19

A study on in-house and outdoor (storage) acidification and a subsequent storage period of 12 weeks showed reductions in CH4 emissions of over 90%.9 Other studies on pig and cattle Slurry reported reductions between 60 and 98%, with higher reduction potentials for pig Slurry and at lower temperatures.9,14,20,21

Nitrates (water): Trials on in-field acidification have shown a decrease in leaching of NO3- of 18%.16 However, effects on nitrate leaching mainly depend on whether the additional N in the Slurry is viewed as mineral fertiliser substitute or as a mean to apply more N to the field overall – keeping mineral N fertiliser rates constant.

Phosphorus (water): Generally, the effect on phosphorous losses is very low. As for nitrate leaching, it also depends on the N fertilisation scheme. If due to the higher N concentration and thus a shift in the N:P ratio of the Slurry towards N, less P is applied on the same area, then reductions in P leaching could be achieved.

Particulate matter: Given the decreased emissions of ammonia, also particulate matter formation is lowered. However, direct particulate matter formation is not impacted.

3. Resilience to climate change

Carbon footprint: Decreased N2O and CH4 emissions lead to a lower global warming potential due to direct emissions from the Slurry. However, additional requirements in energy (due to mixing) and material (for instance the acid) will lead to additional emissions of greenhouse gases

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in other sectors. Further, if the pH of a soil decreases due to acidification, additional lime will be required and applied, potentially resulting in CO2 emissions from dissolution.

Non-renewable energy consumption: The energy consumption for indoor and outdoor acidification processes is assumed to be 3 and 1.2 kWh/t, respectively.1,2 The mixing typically consumes either tractor diesel or non-renewable energy consumption from the grid.

Soil quality: Acidified slurry can potentially lower the pH of the soil to levels below the optimum for plant development (see below). This depends on the soil buffer capacity, the concentration at which Slurry is spread on the field, and the requirements of cultivated crops. The effect of applying acidified Slurry depends not only on the Slurry itself but also on the soil's buffer capacity.3 On soils with low buffer capacity, liming might be necessary to keep pH levels within a range optimal for plant development. The Danish agricultural advisory and research organisation SEGES recommends to apply an equivalent of 75 kg of agricultural lime (75% CaCO3) per hectare and year, if the manure is acidified with 1 L of sulphuric acid per ton and applied at a rate of 30 t/ha.8

Renewable energy production: Unimpacted.

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RL13.LL10 Anaerobic digestion strategies for optimized nutrient and energy recovery from animal manure

BRIEF DESCRIPTION TECHNOLOGY: Small-scale AD of agroresidues (e.g. crop residues, pig manure) can help to decrease environmental issues and increase the amount of renewable energy.

REFERENCE AGAINST WILL BE AVALUATED: Manure / crop residues management without processing.

Expected effect in relation to the reference scenario:

Note: The descriptive information written below is available in https://www.inagro.be/brochurekleinschaligevergisting. References are not directly included in the text but listed at the end.

1. Use of Primary Resources

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Rock phosphate: No effect is expected on a reduction or increase of rock phosphate, since all of the phosphate that is in the input material of the biogas plant is still available in the resulting digestate. In fact, the amount of nutrients (N, P, K) remains unchanged during the AD process.

Natural gas: Naturals gas is assessed as source to produce mineral fertilizers, thus is not impacted by the technology.

Nutrients recovered: The amount of total N will decrease somewhat, but this is compensated by the fact that the amount of mineralised N will increase due to the AD process. Therefore, this N is better available for crops and thus it is a good fertilizer. Nevertheless, some of the carbon will be converted to biogas (CO_2 and CH_4), leading to a decrease in organic material.

Oil: There will be a small increase in the amount of oil, since some oil will be necessary for the engine.

Water: There is no impact in water compared to the baseline.

2. Emissions to the environment

Methane (air) and Nitrous oxide (air): Emissions by applying small scale AD are expected to decrease strongly since the storage time of manure and crop residues will decrease strongly. The CH_4 will not be emitted in the stable, but will instead be valorised as renewable energy. Research showed that on dairy farms, methane emissions can be reduced with up to 70% by applying small-scale AD compared to conventional manure treatment. When looking at the total GHG-emissions, it can be concluded that up to 50% of the emissions can be reduced by applying this technique (Vergote et al., 2020). An important note here is that this figure is strongly case dependent and that the management of the installation is very important, since this 50% reduction can strongly decrease in case of bad management. Similar reduction rates are expected in the case pig manure is being fed to a small scale AD plant. However, this still needs to be quantified.

Ammonia (air): Less emissions due to shorter storage time and (in the case of an adapated stable system for pig manure), separated manure.

Nitrates (water): Since the nitrogen is more mineralised, it is better available for crops, thus leading to less nutrient leaching.

Phosphorus (water) and Particulate matter: The indicator is not evaluated by the technology, but may have impact.

3. Resilience to climate change

Carbon footprint and Renewable energy production: Heat and electricity as biogas will strongly increase. It is expected that this technique will have a positive impact on the carbon footprint, due to reduced GHG emissions and the production of renewable energy.

Soil quality: The remaining OM is more stable than raw feed, which might consequently lead to a positive impact on soil quality by repeated application.

Non-renewable energy consumption: A reduction non-renewable energy consumption is expected, since renewable energy is produced. Nowadays, biogas from a small scale AD plant is mostly valorised by a Combined Heat and Power Unit (CHP), producing heat and electricity. Therefore, the amount of electricity will be reduced strongly by using this technique. However,

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biogas upgrading is gaining more and more attention nowadays. Upgraded biogas (= biomethane) can replace natural gas, but until now, biogas upgrading is not cost-effective on small scale.

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RL13.LL48 Recovery energy from poultry manure and organic waste through anaerobic digestion

BRIEF DESCRIPTION TECHNOLOGY: Converting poultry manure and organic waste through anaerobic digestion to obtain biogas.

REFERENCE AGAINST WILL BE AVALUATED: Management of unprocessed poultry manure

1. Use of Primary Resources

The production of biogas means a renewable energy source as well as a provision of digestate for fertilizing, which the consequent reduction of primary resources, oil, natural gas and increase of nutrients recovered (Balat M. and Balat H., 2009; Khan et al., 2017; Baştabak et al., 2020).

Natural Gas, Oil: Compared to the baseline scenario, no changes are expected in the technology.

Rock phosphate: Effect unknown because it depends on the amount of phosphorus recovered and the amount needed by the crop.

Nutrients recovered: Digestate contains many valuable nutrients, including nitrogen (N), phosphorus (P), and potassium (K), which improved soil physicochemical and biological properties.

Water: The indicator is not impacted by the technology comparing to the baseline.

2. Emissions to the environment

Ammonia (air): The treatment of the manure will reduce ammonia emissions.

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Nitrous oxide (air) and Methane (air): Anaerobic digestion resulting in low greenhouse gas emissions in comparison other manure treatment options such as: composting or storage (Stürmer et al, 2021).

Nitrates (water) and Phosphorus (water): The technology does not cover these indicators, but it must be investigated since manure treated can promote a reduction of nutrient losses when used compared to manure not treated.

Particulate matter: Not assessed by the technology.

3. Resilience to climate change

Carbon footprint and Renewable energy production: Production of biogas means a reduction on the contribution to climate change, directly or indirectly by the substitution of fertilizers replacing by digestate as well as converting organic substrate into useful energy sources (Khan et al., 2017).

Soil quality: Digestate can have a positive effect on soil poperties.

Non-renewable energy consumption: More electricity is consumed, but it is balanced by the biogas produced.

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RL15.LL24 Adapted stable construction for separated collection of solid manure and urine in pig housing (followed by separate post-processing)

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

BRIEF DESCRIPTION TECHNOLOGY: The technology is about an adapted stable construction to separate pig manure at the source so there is a faecal fraction and urine instead of pig slurry. The separated manure is removed daily from the pig housing.

REFERENCE AGAINST WILL BE AVALUATED: Conventional manure management without processing steps.

Effect in relation to the reference scenario:

1. Use of Primary Resources

Rock phosphate and Natural Gas: Changes are not expected.

Oil: No changes are expected.

Nutrients recovered: This technique will have a positive impact on the recovery of nutrients because of the direct separation of the faecal manure and the urine at the source. A N rich urine fraction and a P rich solid fraction can be obtained (Fangueiro et al., 2008). The working principle of the VeDoWs (Vermeulen Dobbelaere Welfare System) adapted stable construction is based on this aspect: In an adapted stable construction VeDoWS (Vermeulen Dobbelaere Welfare System), pig manure is primary separated into solid manure and urine in the stable. The separation occurs by means of a partly-slatted floor system. Underneath the slatted floor, a shallow cellar is constructed, where the primary separation of urine and solid manure occurs. The cellar consists of two inclining parts with an aperture of 18 to 22 mm in the centre. Using a scraper, the solid manure is removed from the cellar every day. Through the scraping action, the pig urine trickles down to a separate collection channel.

Water: There is a reduction in water use.

2. Emissions to the environment

Ammonia (air) and Methane (air): Source separation technologies of pig manure such as a belt system or filter nets has been shown to reduce environmental impacts (Ogink et al., 2000; Van Kempen et al., 2003). These technologies reduce NH_3 emissions up to 75%, CH_4 emissions up to 80%, and odour emission up to 74%, when compared to conventional manure management systems (Aarnink et al., 2007; Lachance et al., 2005; De Vries et al., 2013). In the VeDoWS stable system, the average value for NH_3 and CH_4 emissions is 1.2 kg/animal place/year and 0.8 kg/animal place/year, respectively. The odour was estimated to be around 7.8 odour units/animal place/s, while this value is 29.2 odour units/animal place/s in normal circumstances (Vermeulen, 2019).

Nitrous oxide (air): No storage of manure in pig house. N_2O emissions during field application will be higher when applying pig Slurry compared to separated manure and digestate.

Phosphorus (water) and Nitrates (water): Changes are not expected.

Particulate matter: Changes are expected, but not measured.

3. Resilience to climate change

Renewable energy production: Renewable energy production is possible if the faecal fraction is transported to an AD plant. Because of the separation, the biogas potential of this faecal fraction is better than the non-separated, conventional pig manure. Renewable energy can be produced by the production of electricity and heat during AD of the faecal fraction of pig manure.

Non-renewable energy consumption: The system requires some electricity for the manure scrapers, but on the other hand there is also a reduction in electricity consumption. This is because this system is recognised as a low ammonia emission system, and therefore an end-of-pipe technique like air scrubbing is no longer necessary.

Soil quality: No changes are expected.

Carbon footprint: Although there is more transport needed with this system, the overall impact on the carbon footprint is beneficial: There are less N losses because of the separation process, while the conventional system has more emissions during storage of the manure.

Effective SOM: Changes are expected, but not measured.

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RL15.LL11 Recycling fibres of manure as organic bedding material for dairy cows

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

BRIEF DESCRIPTION TECHNOLOGY: The technology is about recycling fibers of manure as organic bedding material for dairy cows. Also there is a long list solution about an adapted stable construction to separate pig/cattle manure at the source so there is a faecal fraction and urine.

REFERENCE AGAINST WILL BE AVALUATED: Conventional manure management without processing steps

Expected effect in relation to the reference scenario:

1. Use of Primary Resources

Rock phosphate, Oil, soil quality and Natural gas: Not relevant for the technology.

Water: Compared with the liquid manure system is a reduction in water use.

Nutrients recovered: Nutrients are recycled in a closed system , therefore the nutrients recovery increase also the renewable biomass.

2. Emissions to the environment

Ammonia (air) and Nitrous oxide (air): Manure separation reduce NH_3 and N_2O emission.

Methane (air): As volatile solids are separated, storage of the solid part limits the CH_4 emission and the natural crust on the surface of storage tank reduce aeration.

Particulate matter: A reduction of particulate matter occur due to manure separation. The separation efficiency is different from the adapted technology e.g. screw press or centrifuge.

Nitrates (water) and Phosphorus (water): The nitrates and phosphorous in water changes (increase or decrease) are not relevant as the process is about manure separation. Manure leakages in the barn and manure storage after separation are not considered. The nutrient content of separated manure and emissions to the environment is available at https://lpelc.org/manure-separation-bedding-and-nutrient-recovery/.

3. Resilience to climate change

Carbon footprint: The reduction of the carbon footprint occurs due to manure separation and recirculation (bedding use).

Non-renewable energy consumption: Electricity consumption for manure separation process is different for farms with digestate production and green energy production (energy balance) from farms without green energy production. For some farms is an electricity use reduction for others an electricity use increase. On the energy use of manure separators information is available at S. Fournel at all: Production of recycled manure solids for bedding in Canadian dairy farms: I. Solid–liquid separation, in J. Dairy Sci. 102:1832–1846 https://doi.org/10.3168/jds.2018-14966

Soil quality: No changes are expected.

Renewable energy production: The renewable energy production take place only at farms having biogas unit (green energy production).

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RL15.LL8 Acid leaching of P from organic agro-residues in order to produce OM-rich soil enhancers and P fertilizers

BRIEF DESCRIPTION TECHNOLOGY: Through processing the regional manure surplus is refined into different products, instead of being exported outside the Netherlands. One of the processes is extraction of the phosphate from the thick fraction, through acid leaching, which results in struvite, which can replace mineral P fertilizer, and an organic rich soil improver, which can be used in the region.

REFERENCE AGAINST WILL BE AVALUATED: The current practice where the surplus pig manure is exported and the organic matter in the exported manure is not used locally in the region

Effect in relation to the reference scenario:

1. Use of Primary Resources

Rock phosphate, Natural Gas: Carbon rich soil enhancer and P fertilizer are products that result from processing agro-residues in a digestion plant. The P-product that results from the digestion plant has the same characteristics and fertiliser performance as to mineral fertiliser (Sigurnjak et al., 2019) and can therefore replace mineral fertiliser.

Nutrients recovered: This solution pays highest importance to nutrient recovery.

Oil: Fuel can be saved by processing pig manure and other agro-residues in digestion plants near the farm and the resulting products can be applied within the region. Schoumans et al. (2017) predicts a P surplus reduction of 33% when all pig manure of the province Gelderland (Netherlands) is processed. This solution can save fuel by processing pig manure and other agro-residues in digestion plants near the farm and applying the resulting products within the region.

Water: No changes are expected in this indicator.

2. Emissions to the environment

It depends on the technology and the product whether the environmental impact of manure processing increases or decreases (De Vries et al., 2012). Reducing manure storage time is seen as the most cost-effective emission reduction option (Hilhorst et al., 2002).

Ammonia (air), Nitrous oxide (air), Methane (air) and Particulate matter: No effect expected.

Nitrates (water): Increasing the soil organic matter content through carbon rich soil enhancers will increase the binding capacity of soil particles to nitrates (Cambardella and Elliott, 1994). This will reduce the N leaching to ground -and surface water.

Phosphorus (water): Recovering phosphorus avoids phosphorus leaching.

3. Resilience to climate change

Carbon footprint: This innovation will reduce the CO_2 emissions related to manure transport and the production of mineral fertiliser. Processing manure near livestock farms, and applying the bio-based fertilisers locally at arable farms will reduce the carbon footprint (De Vries et al., 2012).

Soil quality: The organic rich soil improver will enhance soil biological, physical and chemical properties (Banger et al., 2010).

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

Non-renewable energy consumption: However, manure processing costs a lot of energy. Therefore, this solution has a negative effect on the electricity use.

Renewable energy production: As a result of the combination of manure processing with anaerobic digestion, biogas is produced, which delivers renewable energy.

RL14.LL61 Tailor made digestate products (tool development)

BRIEF DESCRIPTION TECHNOLOGY: A tool will be developed in order to compare different digestate treatment technologies and their impact on the (nutrient) composition of the final (digestate) products. Considering a tool to be prepared based on comparing different types of technologies the realization of expected effect corresponding to dashboard indicator parameters is not certain yet. At the present state of work progress, it is quite impossible to state clearly the impact – as it can go either way : e.g. it can increase or decrease water consumption etc.

REFERENCE AGAINST WILL BE AVALUATED: non treated digestate.

Expected effect in relation to the reference scenario:

1. Use of primary resources

Rock phosphate and Nutrients recovered: Most technologies used in the tool focus on nutrient recovery - so P recovery instead of using Rock Phosphate. The tool that will be developed will focus on the recovery of nutrients in “tailor-made” digestate products. Therefore, it is to be assumed that by implementing the tool, people will be triggered to actually install technologies that will recover P and N as a “digestate product”. Given that these digestate products can be recovered, it is to be assumed that the rock phosphate consumption will go down.

Natural gas, Oil: No changes are expected.

Water: Depending on the technology assessment, water might be recovered or consumed.

2. Emissions to the environment

Ammonia (air): Better treatment, lower emissions. When disposing the raw digestate as such (= reference scenario), the nutrients will be emitted to environment (soil and air). Therefore, when evaluating different technologies in the Nutri2Cycle-tool what would then lead to the actual implementation of the technology, it will be in a much better controlled way. Also, some nutrient-rich flow might be optimised even further to prevent the uncontrolled emissions to the environment.

Nitrous oxide (air) and Particulate matter: Changes are expected, but not measured.

Nitrates (water): More recovery -> better control over N

Phosphorus (water): More recovery -> better control over P

3. Resilience to climate change

Carbon footprint and Effective SOM: No changes are expected.

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

Non-renewable energy consumption: On the other hand, when implementing an additional technology (as the reference scenario is the disposal of (raw) digestate (i.e. without a treatment) will always increase the consumption of some other primary resources (e.g. electricity).

Soil quality: No changes are expected.

Renewable energy production: In case the “tailor made” digestate products would result to have a higher market value than the raw digestate (= reference scenario), this might be an incentive to increase the capacity of the biogas plants, what in turn would increase the production of biogas (= renewable energy).

RL18.LL32 Annual nutrient cycle assessment (ANCA) system for dairy farms

BRIEF DESCRIPTION TECHNOLOGY: Management tool to optimise nutrient cycles

REFERENCE AGAINST WILL BE AVALUATED: Previous data on nutrient use of the own farm without use of ANCA system.

Expected effect in relation to the reference scenario:

1. Use of Primary Resources:

Rock phosphate, Natural gas, Water: Changes are expected, but it depends on the measures taken by the farmer.

Oil and Non-renewable energy consumption: No changes are expected when using the technology.

Nutrients recovered: The principle working of the ANCA is that it connects different parameters throughout the entire dairy farm production cycle. Involving circular interactivity between: cattle, manure, soil, and crop (roughage/cattle feed).

2. Emissions to the environment:

Ammonia (air), Nitrates (water), Phosphorus (water): The ANCA system focusses on improving nutrient use and reducing losses. It reduces emissions of nutrients (nitrogen/phosphorous) to air, soil and water.

Nitrous oxide (air), Methane (air), Particulate matter: Changes are expected, but it depends on the measures taken by the farmer.

3. Resilience to climate change:

Carbon footprint: The ANCA system takes into account the CO2 emissions related to the activities of the farmer. Farmers receive a CO2 footprint dashboard showing the direct results of their actions.

Soil quality: The principle working of the ANCA is that it connects different parameters throughout the entire dairy farm production cycle. Involving circular interactivity between: cattle, manure, soil, and crop (roughage/cattle feed).

Non-renewable energy consumption: No changes are expected when using the technology.

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

Renewable energy production: No changes are expected.

Research Line 2. Innovative soil, fertilisation & crop management systems & practices

RL1.LL16 Using digestate, precision agriculture and no-tillage focusing on OM stocking in an area

BRIEF DESCRIPTION TECHNOLOGY: Use Anaerobic Digestion, mainly from sewage Sludge, coupled with ammonia stripping/scrubbing to produce a soil improver and a fertilizer exploited with mininum tillage and precision farming technology on rice crop.

REFERENCE AGAINST WILL BE AVALUATED: Traditional crop system and mineral fertilization on rice crop.

Proposed technology is focused on the use of Anaerobic Digestion (AD) coupled with ammonia stripping/scrubbing, to produce a soil improver and a fertilizer mainly from sewage Sludge. This product is exploited with minimum tillage and precision farming technology on rice crop. In such sense, this innovative process will be evaluated against a traditional crop system and mineral fertilization on rice crop scenario.

In particular, adopting of described techniques will led to an effect on different aspects, which can be categorized into four parameter categories: use of primary resources, emissions to the environment, resilience to climate change, productivity.

1. Use of primary resources

Rock phosphate: Use of digestate as fertilizer can greatly reduce the exploitation of rock phosphate, due to the fact that all phosphorus needed for crops comes from digestate itself.

Natural gas: Haber-Bosch process, used to fix most of nitrogen used in agriculture, is accounted for 3-5% of the world's natural gas consumption. Hence so, AD can greatly reduce natural gas consumption, due to simultaneous production of gas and digestate, which is a nitrogen based fertilizer (Smith, 2002).

Oil: Minimum tillage is also well known to be oil saving compared to traditional tillage, since tillage-related operations are energy intensive (Calcante and Oberti, 2019; Koga et al., 2003).

Water: We don’t expect to find any difference against traditional crop system for what concerns soil water content and retention, at least not in the short term (Mupangwa et al., 2007).

Nutrients recovered: Other positive effect of the production and use of digestate is on nutrient recovery, due to the fact that N, P and many micronutrients in field have as only source the fertilizers produced by the solution. If digestate is applied with direct incorporation into the soil, it can provide plant available N corresponding to their NH_4^+-N content plus a small part (10–20%) of the organic nitrogen fractions (Möller and Müller, 2012).

2. Emissions to the environment

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

Ammonia (air), Nitrous oxide (air), Methane (air): One critical point on the use of digestate is the risk of gaseous emissions during spreading and possible nitrate leaching to groundwater. As part of the proposed solution, a study of emissions in field, referred against tradition cropping and untreated soil, is going on, and results will be ready soon. However, previous works encourage the idea that sub-surface injection of digestate lets to a reduction of ammonia emissions to levels that are similar to those obtained by conventional chemical fertilization (Riva et al., 2016). Other works suggested that also methane and dinitrogen monoxide emission could have a relatively low impact (Czubaszek and Wysocka-Czubaszek, 2018).

Nitrate (water): For what concerns nitrate leaching previous works have suggested that with a normal nitrogen fertilization, this element is completely metabolized by microbial populations, ensuring low nitrate content in depth (Zilio et al., 2020).

Phosphorus (water): No literature have been found for what concern phosphorus leaching under digestate fertilization, but this aspect is analysed in current experiment too.

Particulate matter: We also expect an effect of reduction in particulate matter emissions, since minimum tillage decrease the consumption of fuel in field and consequently also the production of particulate.

3. Resilience to climate change

Carbon footprint: Combination of AD and minimum tillage can also bring significant energy savings. Our proposed solution can have a positive effect on resilience to climate change. In particular, carbon footprint can be reduced with the adoption of minimum tillage, due to lower fuel requirements, with the use of renewable fertilizers (N and P), which reduce energy consumption, and with the recovery of electrical energy from biogas (Gan et al., 2011) (Bacenetti and Fiala, 2015)

Non-renewable energy consumption: Electricity used in the technology will be balanced by the biogas produced.

Soil quality: On the other side, we expect an increase of soil quality with the application of amendments and use of minimum tillage techniques, mainly due to increase of organic matter content in soil (Tambone et al., 2009).

Renewable energy production: Proposed solution also have a positive effect on the production of renewable energy, since some of biogas produced through AD is recovered and exploited to produce electrical energy. Biogas produced can be converted to heat and electricity in a CHP unit, and part of the produced energy can be used at the biogas plant, e.g. for reactor heating and mixing; electricity consumption of the biogas plant has been estimated as 3% of the biogas produced (Pöschl et al., 2010).

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RL1.LL17 Crop farmer using a variety of manure and dairy processing residues to recycle and build soil C, N, P fertility

BRIEF DESCRIPTION TECHNOLOGY: Application of manure, dairy food processing by-product, and nutrient rich recycling derived fertilisers (lime treated pig Slurry solids, struvite and ashes) to arable crop rotation and grassland pasture to produce livestock feed and improve soil organic matter and carbon.

REFERENCE AGAINST WILL BE AVALUATED: Crop production with mineral fertilization.

Mineral fertilisers have proven to be a convenient and a consistent source of nutrients for many years. However, there is a growing interest in the potential long-term soil health benefits of including other sources of nutrients such as organic or recycling derived fertilisers. These fertilisers often deliver other nutrients in addition to nitrogen, phosphorus and potassium to soil along with carbon. The European Commission (EC) has recently revised the EU Fertiliser

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Regulation (EC, 2019), expanding its scope to include secondary-raw-material-based fertilising products to support the shift to sustainable agriculture and a "circular economy" (Huygens et al., 2018).

Incorporation of organic and recycling derived fertilisers is likely to become an increasingly essential part of the nutrient supply which farmers will closely manage in the future. However, there are open questions regarding the benefits, challenges and practicalities of incorporating such options into cropping fertiliser programmes. As part of the EU H2020 funded Nutri2Cycle project, we have established on-farm multi-year research and demonstration trial in agronomic trial plots in two land management systems – I) grasRLand and II) arable farmland. The footprint of the both study sites will be used to monitor longer-term effects of manure and/or bio-based product incorporation into this system on C, N and P cycling. The case has potential to be used as a lighthouse demo as it will involve a farmer, his advisor and the research element.

1. Use of Primary Resources

Rock phosphate, Soil quality: Some studies on the balanced use of organic-inorganic fertilization showed the potential for higher crop yield, reducing chemical based fertiliser usage, and improving soil quality (Geng et al., 2019; Zhao et al., 2016). In particular, the EU needs safe recycling sources of phosphorus (P), as Europe lacks natural phosphate rock deposits and mainly depends on imported P. Exploring alternatives to mineral P fertilisers and increased recycling of P may substantially contribute to the reduction of demand for fossil P resources and the dependency on the importation of P from other countries (Reijnders, 2014). The present study will generate new knowledge on P bioavailability for a number of new bio-based or recycling derived fertilisers, and also provides an option for balanced application of bio-based and chemical fertilisers to meet the demand of required crop nutrients like N, P, K and S.

Natural gas: Therefore, the outcomes of this study are expected to help reduce chemical fertiliser use (especially P, N, K, and S fertilisers) which will reduce the pressure on using fossil fuel (e.g. natural gas) to manufacture synthetic mineral fertilisers. Indeed, the results of this study from the first year trial in 2019 showed that yield for the bio-based fertiliser programmes were equal to conventional mineral fertiliser programmes with bio-based fertilisers showing potential to efficiently deliver P and other nutrients to crops. Significant fertiliser cost savings of 23-37% on mineral fertiliser were achieved without compromising yield (Ashekuzzaman et al., 2020a).

Oil: However, transportation of some locally available bio-based products like dairy processing Sludge, poultry/broiler manure potential for land application might still need to transport to a longer distance than their current application in the vicinity where they are generated. This will involve substantial transportation as these materials have lower bulk densities compared to chemical fertilisers. On the other hand, some processed recycling fertilisers like struvite, biochar and ashes might have similar effect like chemical fertilisers in terms of transporting them to the farmyard.

Nutrients recovered: The combined use of bio-based products with conventional chemical fertiliser would increase nutrients being recycled closing the C, N and P loop in the agro-ecosystem which in the long-term is expected to benefit soil quality in terms of increasing soil C and organic matter.

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Water: This integrated nutrient management practice is unlikely to have any different effect on irrigation water usage as compared to use of only chemical fertilisers.

2. Emissions to the environment

Ammonia (air), Nitrous oxide (air) and Particulate Matter: Handling and spreading of organic fertilizers like cattle slurry, poultry manure and dairy processing sludge may pose an environmental risk, not only because of leakage of nitrate to recipient waters but also because of substantial gaseous losses of ammonia (NH3) and the greenhouse gases (GHG), nitrous oxide (N2O) and methane (CH4) (Rodhe et al., 2006).The emissions of NH3 and N2O related to organic N degradation and transformation from application and storage of bio-based or recycling fertilisers is dependent on the type and form being applied. For example, land spreading of cattle Slurry, poultry manure and dairy processing Sludge might involve with significant NH3 volatilisation as the majority of such emissions originate from livestock waste streams (housing, storage and landspreading of manures (Burchill et al. 2017). Re-deposition of volatilised NH3 is an important source of N for the production of N2O via biological nitrification of ammonium (NH4+) and subsequent denitrification of nitrate (NO3-) (Kavanagh et al., 2020). NH3 is also an important precursor of forming fine particulates (particulates less than 10 µm, PM10 and less than 2.5 µm PM2.5) (Melynda et al. 2016). However, struvite, ash and lime treated pig Slurry solids are expected to emit negligible or no NH3 gases because they contain small quantity or no N. In particular, struvite contains only about 6% N and due to its slow releasing characteristics, plant can uptake most of the N without any losses after application in the soil (Rahman et al., 2014).

Methane (air): The increasing use of organic or recycling fertilisers can prevent fossil energy emission associated to the industrial production of synthetic chemical fertiliser inputs and promote soil C accumulation (Aguilera et al., 2015). As explained above ("the increasing use of organic or recycling fertilisers can prevent fossil energy emission associated to the industrial production of synthetic chemical fertiliser inputs and promote soil C accumulation (Aguilera et al., 2015)"), it can be assumed that reduced methane emission due to less use of chemical fertiliser (i.e. less emission from fossil fuel burning) which is likely to outweigh methane emission from organic or bio-based fertiliser application. Hence, positive effect on methane.

Phosphorus (water): The runoff loss potential of P to waterbodies was observed to be significantly less from struvite (recycling derived product) compared to mineral monoammonium phosphate (MAP) fertiliser (Everaert et al., 2018). Also, the P loss potential from different bio-based fertilisers (e.g. cattle Slurry, biosolids and dairy processing Sludge) was reported in the range between 0.3 and 17% which are significantly less than a mineral P fertiliser application (e.g. MAP showed 42% lost due to runoff) (Ashekuzzaman et al., 2020b; Everaert et al., 2018).

Nitrates (water): Leakage of nitrate to recipient waters might be associated with application of cattle slurry, poultry manure and dairy processing sludge. However, such leaching is not expected from struvite, ash and lime treated slurry solids.

3. Resilience to climate change

Carbon footprint: In general, the dominance of non-renewable energy emissions (due to fossil fuel use) in the global warming potential of agricultural crop production suggests that strategies aiming to reduce resource consumption would successfully contribute to climate change mitigation (Aguilera et al., 2015). However, emission balances between fossil fuel use input and direct field applications of organic fertilisers need to be assessed by life cycle assessment (LCA) approach to demonstrate the overall greenhouse gas balance. Some studies show that organic farming could reduce crop emissions by 36–65 % (Aguilera et al., 2015). As the proposed study aiming to reduce chemical fertiliser usage, it is expected that this will help to reduce carbon footprint by cutting down fossil fuel related inputs.

Non-renewable energy consumption: No impacts are expected in this indicator.

Renewable energy production: No changes are expected.

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RL1.LL71 Practices for increasing soil organic matter content

BRIEF DESCRIPTION TECHNOLOGY: This description refers to the long-list solution 71 (Practices for increasing soil organic matter content in Dutch soils). For a sub-set of arable farms from the Dutch Smart Land Use programme. the soil carbon model RothC will be used to assess the potential for soil carbon sequestration for a selection of practices, which comprise:

• Use of cover crops

• Improved crop rotation with more crops that have higher C input and less soil disturbance (e.g. cereals, temporary grass, lucerne)

• Increased use of compost or solid manure

• Reduced tillage

REFERENCE AGAINST WILL BE AVALUATED: The reference scenario will be the current management without the practices aimed at increase soil organic matter.

1. Use of primary resources

Rock phosphate: Only limited effects are expected on the use of primary resources. In case of increased use of organic fertilizers, there is less need for mineral P fertilizer.

Natural gas: On the longer term less mineral N fertilizers might be required when SOC builds up and nitrogen cycling will improve. However, in the Netherlands there is already a high use of animal manure, mainly as slurry, therefore the replacement effect for nitrogen will be small.

Oil: The use of reduced tillage will require less diesel compared to conventional tillage.

Water: Therefore, there is also a positive effect on the resource water, as more water can be retained in the soil with a higher organic matter content, although this effect is not very large (Ghaley et al., 2018).

Nutrients recovered: This measure comprises a range of practices with the objective ton increase the soil organic matter content in Dutch arable soils. For a sub-set of arable farms from the Dutch Smart Land Use programme the soil carbon model RothC will be used to assess the potential for soil carbon sequestration for a selection of practices, including the use of cover crops, improved crop rotation with more crops that have higher C input and less soil disturbance (e.g. cereals, temporary grass, Lucerne), increased use of compost or solid manure and reduced tillage.

2. Emissions to the environment

Ammonia (air), Methane (air), Particulate matter: The effect of the practices on emissions to the environment is uncertain.

Nitrates (water), Phosphorus (water): Increased soil organic matter content might better retain nutrients in the soil, but the effect on leaching depends whether the release of nutrients and demand of plants is in balance. In literature variable effects on nitrate leaching are found.

Nitrous oxide (air): One of the risks is increased emissions of N2O, as easily degradable organic matter is an energy source for denitrification. The presence in soil or application of organic matter via manure or crop residues affects denitrification and N2O emission. A recent review by

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Guenet et al. (in press) shows that the climate mitigation induced by increased SOC storage is generally overestimated if associated N2O emissions are not considered but, with the exception of reduced tillage, that it does not offset the sequestered CO2 in the soil.

3. Resilience to climate change

Caron footprint: Increasing soil organic matter practices contribution to soil carbon sequestration and help to mitigate the carbon footprint of arable agriculture.

Non-renewable energy consumption and Oil: The energy use might change a bit, but very much depends on the specific measure and local circumstances at the farm.

Soil quality: All practices will contribute to improved soil quality, as soil organic matter is key for many other soil functions, like nutrient cycling, water retention and habitat for soil biota.

Renewable energy production: If crop residues are directly incorporated in the soil, the carbon is no longer available for bioenergy (e.g. for biofuels or biogas).

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RL2.LL21 Catch crops to reduce N losses in soil and increase biogas production by anaerobic co-digestion

BRIEF DESCRIPTION TECHNOLOGY: Manure management at a biogas plant, use of digestate as organic fertilizer to a maize + catch crop rotation, use of the maize harvest as livestock feed and use of the catch crop harvest in anaerobic codigestion.

REFERENCE AGAINST WILL BE AVALUATED: Maize crop production with mineral fertilization.

Expected effect in relation to the reference scenario:

1. Use of Primary Resources

Rock phosphate and Natural gas: Digestate will replace the use of mineral fertilizers, with consequent reduction of rock phosphate and natural gas used in their manufacture (Montemayor et al, 2018, gg 402; Tidåker et al., 2014).

Oil: The inclusion of catch crops involves an increasing of gasoil operations: sowing and harvesting (Montemayor et al, 2018 pg 399).

Water: Catch crops do not required irrigation, therefore not increase or reduction of water needs (Montemayor et al, 2018 pg 399).

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Nutrients recovered: The valorization of manure as fertilizer means a recovering of nutrients (Montemayor et al., 2018, pg 403)

2. Emissions to the environment

Ammonia (air) and Nitrous oxide (air): Digestate management means an increase of ammonia (during storage) and dinitrogen oxide emissions,

Methane (air): It results neutral for methane emissions because in front mineral fertilizer production could mean an increase, but we assume this is compensate by the fresh manure management instead of no management (Montemayor et al., 2018, pg 400).

Nitrates (water) and Phosphorus (water): The use of catch crops has the potential to reduce the loss of nitrates and phosphates to zero

Particulate matter: Increase particulate matter emissions during labour operations. (Montemayor et al., 2018, pg 403)

3. Resilience to climate change

Carbon footprint: The production of renewable energies and substitution of mineral fertilizers will reduce carbon footprint of activity.

Non-renewable energy consumption: More energy is consumed but biogas production means a saving in electricity production (Montemayor et al., 2018, pg 403)

Soil quality: We assume that the growth of catch crops reduces soil erosion because soil cover.

Renewable energy production: For sure there is a renewable energy production at the biogas plant (Montemayor et al., 2018, pg 400).

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Research Line 3. Tools, techniques & systems for higher-precision fertilization

RL19.LL30 Precision farming coping with heterogeneous qualities of organic fertilizers in the whole chain.

BRIEF DESCRIPTION OF THE TECHNOLOGY: The main purpose of using near-infrared sensor (NIRS) is to cope with heterogeneous nutrient contents of liquid manure, in order to optimise nutrient supply according to plant needs and site-specific conditions. Furthermore, tracking of manure transport and documentation of application rates help to improve nutrient management at farm level and to comply with legal frameworks.

The use of Near Infrared Spectroscopy (NIRS) for precision agriculture became more common over recent decades. The technology is dominantly used for estimating soil and crop properties (Mulla, 2013), and less for precision fertilisation. However, Ng et al. (2020) acknowledges the potential of NIRS sensors for precision fertilisation.

REFERENCE AGAINST WILL BE EVALUATED: Current practice of applying liquid manure without precise information about nutrient content and traditional nutrient testing and storage time.

1. Use of primary resources

The innovation will use a NIRS sensor to investigate the nutrient content and heterogeneity of liquid manure during fertilisation. Nutrients can more precisely be applied to the plant needs due to this innovation.

Rock phosphate, Natural Gas and Nutrients recovered: This will increase the nutrient use efficiency of organic fertilisers and reduce the use of mineral N and P fertiliser. Therefore, it will have a positive impact on the reduction of non-renewable chemical fertilisers like rock phosphate.

Oil and Water: No changes are expected.

2. Emissions to the environment

Ammonia (air), Nitrous oxide (air), Methane (air), Particulate matter: No changes are expected.

Nitrates (water) and Phosphorus (water): Applying liquid manure to the plant needs can reduce the risk for N and P overapplication, and therefore it can reduce N and P leaching to ground -or surface water. The use of NIRS sensors for precision fertilisation of mineral N and P has shown its success in terms of productivity and reducing N and P losses to ground -and surface water (Stamatiadis et al., 2018). There is no need to wait for laboratory results and therefore the manure storage time can be reduced, which can have a positive effect on atmospheric emissions. During application, the atmospheric emissions depend on the complex interaction between application rate and technique, manure composition, soil conditions and climate (Robert, 2002).

3. Resilience to climate change

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

Carbon footprint: The innovation enhances fertilization optimisation by minimizing over- or under-fertilisation. These innovations can reduce the carbon footprint (Liu et al., 2016).

Soil quality: When the application of this technology results in a reduced use of mineral fertilisers, this technology can also enhance the soil quality (e.g., soil structure, soil water holding capacity, soil fertility).

Non-renewable energy consumption and Renewable energy production: No changes are expected.

RL20.LL28 Precision farming and optimised application: under-root application of liquid manure for maize and other row crops

BRIEF DESCRIPTION OF THE TECHNOLOGY: mineral N and P fertilizers for under-root application around maize seeds can be replaced by liquid manure to increase nutrient efficiency and to contribute closing the nutrient loops. In poor soils, particularly deficient of P, under-root application ensures that nutrients are available below the soil surface near roots. This innovation aims to replace mineral fertilizer by under-root Slurry application. Therefore, the use of mineral phosphate can reduce and the nutrient recovery can increase.

REFERENCE AGAINST WILL BE EVALUATED: Current practice of using mineral fertiliser for under-root fertilizer application in maize.

1. Use of primary resources

Rock phosphate, Natural gas: This technology stimulates the precise under-root application of liquid manure which can reduce the use of mineral N and P-fertiliser.

Oil: Effects were not measured.

Water: No changes are expected.

Nutrients recovered: Under-root application of slurry replaces mineral N/P-fertiliser, and increases nutrient use efficiency.

2. Emissions to the environment

Ammonia (air), Nitrous oxide (air) and Particulate matter: Slurry injection substantially reduces NH_3 emissions, but it increases N_2O emissions compared to broadcast application (Velthof and Mosquera, 2010). Reduced NH_3 emissions also decrease secondary particulate matter emissions.

Methane (air): No changes are expected on this indicator.

Nitrates (water) and Phosphorus (water): The reduced use of N/P-fertiliser and the increased nutrient use efficiency have a positive effect on the N and P leaching to ground -and surface water. A study of Federolf et al. (2016) tested the injection of Slurry combined with a nitrification inhibitor. This resulted in equal maize yields and significantly higher N uptakes. To increase the P use efficiency, Federolf et al. (2016) recommended injecting the manure prior planting.

3. Resilience to climate change

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

Carbon footprint: By increasing the N and P use efficiency, also the carbon footprint reduces. The combination no-till and injection substantially reduces sediment-bound P losses and NH3 volatilisation (Dell et al., 2011).

Soil quality: Effects were not measured.

Non-renewable energy consumption and Renewable energy production: No changes are expected.

RL20.LL63 Precision fertilization of maize using organic materials

BRIEF DESCRIPTION OF THE TECHNOLOGY: Use of manure for maize fertilization in combination with precision agriculture techniques

REFERENCE AGAINST WILL BE EVALUATED: Compare the use manure (Slurry and solid manure) and mineral fertilisers.

1. Use of primary resources

Rock phosphate, Nutrients recovered, Natural gas: Precision fertilisation using organic fertilisers is much less common compared to mineral fertilisers. Precision fertilisation using organic fertilisers increases the nutrient recovery and decreases the use of mineral fertilisers like rock phosphate.

Water: This innovation may reduce the need for transport and production of mineral fertiliser, and when the carbon content in the soil increases the soil becomes more resilient to draughts which reduces the need for irrigation.

Oil: It is not impacted by the technology.

2. Emissions to the environment

Ammonia (air): Manure application can increase the ammonia emissions, except when it is treated by, for example, acidification.

Nitrous oxide (air): There is no significant difference in N2O emissions when organic or mineral fertilisers are applied (Meng et al., 2005). However, these emissions are strongly related to soil moisture and temperature.

Methane (air) and Particulate matter: Not assessed by the technology.

Nitrate (water) and Phosphorus (water): The application of organic fertiliser using precision agricultural techniques can prevent N and P leaching (Meng et al., 2005).

3. Resilience to climate change

Carbon footprint: Replacing mineral fertilisers by organic fertilisers will reduce the carbon footprint.

Soil quality: Besides minerals, organic fertilisers contain carbon, which enhances soil biological, physical and chemical properties (Banger et al., 2010).

Non-renewable energy consumption: It is not impacted by the technology.

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

Renewable energy production: Not assessed by the technology.

RL21.LL73 Potato growing using only biobased fertilizers with precision agriculture technologies

BRIEF DESCRIPTION OF THE TECHNOLOGY: Field and pot trial to see if extra pig manure refinement steps (separating N and K in pig manure processing) lead to higher potato yield, profit and closing of CNP loops.

REFERENCE AGAINST WILL BE EVALUATED: the non-refined liquid fraction of AD digestate as the biobased fertilizer

1. Use of primary resources

Pig manure can be processed into valuable bio-based fertilisers. Refining pig manure further after anaerobic digestion of the liquid fraction will result in products that have nearly the same characteristics and fertiliser performance compared to mineral fertiliser (Sigurnjak et al., 2019).

Nutrients recovered: Recycling of waste products like manure will stimulate nutrient recovery and help closing N, P and C loops.

Rock phosphate: Using these products in arable farming can reduce the use of rock phosphate.

Natural gas, Oil, Water: No changes are expected.

2. Emissions to the environment

Ammonia (air): It depends on the technology and the product whether the environmental impact of manure processing increases or decreases (De Vries et al., 2012). A significant reduction in ammonia emission can be realized when pig manure processing reduces the manure storage time (Hilhorst et al., 2002). Reducing manure storage time is seen as the most cost-effective emission reduction option (Hilhorst et al., 2002).

Nitrates (water), Phosphorus (water): Applying these bio-based fertilisers using precision fertilisation will decrease N and P leaching to ground -and surface water.

Nitrous oxide (air), Methane (air) and Particulate matter: Changes are expected, but not measured.

3. Resilience to climate change

Carbon footprint: CO2 emissions related to manure transport and the production of mineral fertiliser can reduce when pig manure is processed on or near the pig farm, and when the bio-based fertilisers are applied locally at arable farms (De Vries et al., 2012). These advantages will reduce the carbon footprint.

Non-renewable energy consumption: No changes are expected.

Soil quality: Changes are expected, but not measured.

Renewable energy production: No changes are expected.

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RL22.LL68 Integration of UAV/Drone and optical sensing technology into pasture systems

BRIEF DESCRIPTION OF THE TECHNOLOGY: Use of UAV/Drone and optical sensing technology for precision pasture management, increase N use efficiency and reduce greenhouse gas emissions by avoiding excessive N fertiliser application in urine patches.

REFERENCE AGAINST WILL BE EVALUATED: Typical N fertiliser application in pastures including hot spots due to urine and dung deposits.

1. Use of primary resources

Rock phosphate, Oil, Water: No changes are expected.

Natural gas: This innovation avoids additional application of N at intense N hotspots caused by urine and dung deposits. This will reduce the use of natural gas in relation to a reduced use of mineral N fertiliser.

Nutrients recovered: Less application of N fertiliser.

2. Emissions to the environment

Ammonia (air), Nitrous oxide (air): Less application of N fertiliser.

Nitrates (water): The use of precision fertilisation techniques has shown its success in terms of productivity and reducing N losses to ground -and surface water (Forrestal et al., 2012; Stamatiadis et al., 2018). This innovation will reduce the use of mineral N fertiliser and increase the nutrient use efficiency.

Particulate matter: Changes are expected, but not measured.

Phosphorus (water): No changes are expected.

3. Resilience to climate change

Carbon footprint: The innovation enhances fertilization optimisation by minimizing over- or under-fertilisation. The reduced use of mineral N fertiliser and increased nutrient use efficiency will decrease the carbon footprint (Liu et al., 2016).

Non-renewable energy consumption, Soil quality and Renewable energy production: No changes are expected.

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RL23.LL13 Nitrogen sensor technology to make real-time crop assessment

BRIEF DESCRIPTION OF THE TECHNOLOGY: Tractor mounted N sensor technology (based on vegetative biomass light reflectance) is able to distribute chemical fertilizers and pesticides according to soil nutrient availability and crops nutrition needs.

REFERENCE AGAINST WILL BE EVALUATED: Traditional chemical fertilisation technology without N sensors.

1. Use of primary resources

Rock phosphate, Oil, Water: No changes are expected.

Natural gas and Nutrients recovered: This innovation helps applying N more precisely to the plant needs. This will increase the N use efficiency.

2. Emissions to the environment

Nitrates (water) and Phosphorus (water): The use of precision fertilisation techniques has shown its success in terms of productivity and reducing emissions and leaching (Stamatiadis et al., 2018; Pajares, 2011; Aquino-Santos et al., 2011). Using this sensor for applying mineral N fertiliser or liquid manure to the plant needs using can reduce the risk for N and P overapplication, and therefore it can reduce N and P leaching to ground -or surface water. Especially in areas with a high groundwater table the N leaching will reduce.

Ammonia (air), Nitrous oxide (air): There is expected that this innovation reduces atmospheric emissions as well, because this innovation will be tested in an area dominated by an overapplication of N fertiliser.

Particulate matter: Changes are expected, but not measured.

Methane (air): No changes are expected.

3. Resilience to climate change

Carbon footprint: The innovation enhances fertilization optimisation by minimizing over- or under-fertilisation. These innovations can reduce the carbon footprint (Liu et al., 2016).

Soil quality: Soil quality is expected to increase, but not measured yet.

Non-renewable energy consumption and Renewable energy production: No changes are expected.

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Research Line 4. Biobased fertilisers (N, P) and soil enhancers (OC) from agro-residues

RL3.LL66 Application of digestate in large scale orchards (IPS)

BRIEF DESCRIPTION OF THE TECHNOLOGY: The underlying working principle in the specific case refers to the application of digestate in the beginning of the project. In the phase of soil preparation, the company technologists decided to implement the combination of Ca(OH)2 in concentration of 1,00 t/ha, thick fraction of digestate in concentration of 50,00 t/ha and thick fraction of cattle manure in concentration of 33,00 t/ha. Next to organic fertilizers, 30 grams/plant of mineral fertilizer (NPK 7-20-30) was also applied. The digestate was applied using Strautmann fertilizer spreader. The cattle manure and digestate was applied once in the beginning of the orchard setup and due to the orchard principal used (raised bed) it has not been foreseen to use it again.

REFERENCE AGAINST WILL BE EVALUATED: Orchads using mineral fertilizer.

1. Use of primary resources

Rock phosphate and Natural gas: Since digestate contains nitrogen and phosphorus, reduction in the use of rock phosphate and natural gas can be expected to a certain extent.

Oil: Both digestate and synthetic fertilizers need machinery to be applied, and for the operation of machinery oil is needed.

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Water: Cannot be scored because aim of technology is application of digestate and not production. So, these primary resources do not apply on the case study.

2. Emissions to the environment

Nitrous oxide (air): Investigating the effect of application of digestate on emissions to the environment, studies show that digestate increase N2O emissions. Based on the available literature (Möller and Müller, 2012; Verdi et al., 2019), digestate emits around 23% of N2O more than mineral fertilizers. In a study by Zilio et al. (2021) authors came to a conclusion that digestate emitted less odour than synthetic fertilizer. GHG emissions can be produced and emitted during digestate storage and during its spreading upon the field. So in this technology where the digestate was used in the field we can expect some of the emissions.

Methane: Based on the literature CH4 emissions from digestate are not critical.

Ammonia: Ammonia release and nitrate leaching are still a critical point. Digestate application increase ammonia emissions.

Nitrates (water) and Phosphorus (water): N and P recovered avoiding leaching.

Particulate matter: May have an impact, but it is not measured.

3. Resilience to climate change

Carbon footprint: There will be small effect on reduction of carbon footprint.

Non-renewable energy consumption: Cannot be scored because aim of technology is application of digestate and not production. So, these primary resources do not apply on the case study.

Soil quality: Application of digestate has a medium effect on increase of soil quality. Good practice in soil management and the efficient use of digestate had significant results on soil fertility. Studies show that the Carbon-Nitrogen ratio can be significantly increased because of increase of soil organic carbon. Stable soil fertility parameters had a positive effect on the stable level of nitrogen (indicating reduced leaching effects), positive effect on the concentration of macro-nutrients and inducing increase in phosphorus (Bezzi et al., 2016).

Renewable energy production: Renewable energy production does not apply because as the solution does not focuses on production of digestate, but on application.

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RL3.LL57 Recovered organic materials and composts for precision fertilization of apple orchards and vineyards (ISA)

BRIEF DESCRIPTION OF THE TECHNOLOGY: This solution briefly concerns the use of manure for orchard and vineyards fertilization in combination with precision agriculture techniques.

REFERENCE AGAINST WILL BE EVALUATED: Within each parameter, factors have been selected to evaluate gains and losses of manure application as fertilizer relative to mineral fertilization.

1. Use of primary resources

Natural gas and Rock phosphate: Regarding the use of primary resources, the application of manure as fertilizer will reduce the need for mineral fertilizers (Schröder, 2005), which in turn, will reduce the demand for rock phosphate, which is a finite resource that is being depleted. There will also be a reduction in the use of natural gas that is used for the production of mineral fertilizers.

Oil: Oil impact is assessed due to machinery used. Therefore, it is neutral impact for this technology.

Water: In addition, there will be a reduction of water used for irrigation purposes, due to the increase of soil water holding capacity (Haynes and Naidu, 1998; Adeleye et al., 2010). Manure application improves soil quality, by adding carbon (C) and nitrogen (N) (Meng et al., 2005) and also contributes to the restoration of natural soil reserve.

Nutrients recovered: The use of manure as fertilizer recovers nutrients that could be leached.

2. Emissions to the environment

Ammonia (air): Concerning emissions to the environment, there will be an increase of ammonia (NH3), emissions as a consequence of manure application. However, if manure is treated, such losses may be mitigated, as reported by Chantigny's et al. (2007): the application of treated liquid swine manure (decanted, filtered, anaerobically digested, or chemically flocculated) resulted in an average reduction of 25% in NH3 emissions when compared to raw liquid swine manure, and when anaerobically digested. The impact on NH3 is quite difficult to estimate since it relies on manure treatment or not, but also on the mineral fertilizer used for comparison.

Nitrous oxide (air): Nitrous oxide (N2O) emissions resulting from manure application were also significantly reduced.

Phosphorus (water): At the same time, there is a small risk of phosphorus (P) leaching with the manure application, due to organic P mineralization and low P mobility (Kang et al., 2011).

Nitrates (water): Regarding nitrates (NO3-N), there is a low risk of leaching, due to the slow mineralization of nitrogen from manure, however, during winter, the risk of NO3-N is strongly increased (Nyamangara et al., 2003).

Methane (air): There are no effects on the emission of methane (CH4) to be anticipated. In the case of N2O, such emissions will be reduced with the application of manure in comparison to mineral fertilizers, as seen in Ball et al. (2004) experiments. The authors showed that the application of manure mitigated total N2O emissions over their whole experiment, and most

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importantly, mitigated the initial flux of N2O after heavy rainfall. Although, the authors did not register significant mitigation of carbon dioxide (CO2) and CH4.

3. Resilience to climate change

Carbon footprint: The application of manure is expected to reduce the carbon footprint, by adding a material rich in carbon that will contribute to close the C cycle (and other nutrient loops) and also reduces the carbon footprint, normally associated with the use of mineral fertilizers. Cerutti et al. (2010) did an ecological footprint analysis of swine fertilization, in nectarine orchard, while comparing it with mineral fertilization and came to the conclusions that the latter has a higher ecological footprint: the fertilizer contribution in mineral fertilized systems takes up to 6.6% of the total ecological footprint, whereas in the manure fertilized system only takes up 0,9 to 1,2%.

Non-renewable energy consumption: Not impacted by the technology compared to the baseline.

Soil quality: The manure application improves soil's health by adding carbon, and also contributes to the restore some nutrients natural soil reserve.

Renewable energy production: The technology has no impact on this indicator.

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RL3.LL14 Substituting mineral inputs with organic inputs in organic viticulture (CA17)

BRIEF DESCRIPTION OF THE TECHNOLOGY: Substituting mineral inputs with organic inputs in organic viticulture.

REFERENCE AGAINST TO BE EVALUATED: different crops with agroforestry with mineral fertilization and vineyard without fertilization.

1. Use of primary resources

Rock phosphate and Nutrients recovered: A reduction of Phosphate rock is expected because of the supply of organic P from oil-cake instead of extraction material: oil-cake's P2O5 = 16,2 g/kg Fresh Matter.

Natural gas: On the other hand, an increase of soil quality and recovered nutrients is predictable because of the supply of organic matter for vineyard : oil-cake's OM = 68.2 % fresh matter and its use of oil-cake as a fertilizer, that is taken into account in the fertilization plan.

Oil and Water: No changes are expected.

2. Emisions to the environment

All emissions are considered as unknown, since changes are expected, but not measured yet.

3. Resilience to climate change

Carbon footprint: A reduction of climate change is expected due to carbon storage in soil with the use of oil-cake as a fertilizer.

Soil quality: On the other hand, an increase of soil quality and recovered nutrients is predictable because of the supply of organic matter for vineyard: oil-cake's OM = 68.2 % fresh matter and its use of oil-cake as a fertilizer, that is taken into account in the fertilization plan.

Non-renewable energy consumption and Renewable energy production: No changes are expected.

RL3.LL15 Closing the loops at the scale of farm: using the livestock manure to fertilize the feeding crop on agroforestry plots (CA17)

BRIEF DESCRIPTION OF THE TECHNOLOGY: Substituting external mineral nutrient input from synthetic fertilisers by recycled organic based fertilizers in orchards & agroforestry.

REFERENCE AGAINST TO BE EVALUATED: different crops with agrofroestry with mineral fertilization and vineyard without fertilization.

1. Use of primary resources

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

Rock phosphate and Natural gas: A reduction of phosphate rock is expected as production of organic P from effluents occurs: solid manure's P2O5 = 2.4 g/kg fresh Matter and Slurry's P2O5 = 1.1 g/kg fresh Matter

Oil and Water: Impacts were considered as neutral.

Nutrients recovered: An increase of nutrient recovery because of the use of livestock manure as a fertilizer.

2. Emissions to the environment

All emissions are considered unknown for this technology.

3. Resilience to climate change

Carbon footprint: The agroforestry system allow to stock carbon in the soil's OM with pruning residues and as living stock with the roots and perennial aerial parts. The agroforestry system allow to stock carbon in the soil's OM with pruning residues and as living stock with the roots and perennial aerial parts, therefore a prevision of climate change reduction.

Non-renewable energy consumption: No changes are expected.

Soil quality: Supply of organic matter for arable plot: solid manure's OM = 11.2% Raw Matter. The agroforestry part bring alos orgabic matter but to assess the value is too difficult.

Renewable energy production: In addition, an increase or renewable energy because of the wood production in agroforestry for energy and heat production.

RL4.LL1 Ammonium stripping / scrubbing and NH4NO3 as substitute for synthetic N fertilizers (UGent/Inagro)

BRIEF DESCRIPTION OF THE TECHNOLOGY: The aim of ammonia (stripping-)scrubbing is to produce ammonium nitrate (AN) solution. AN contains total nitrogen (N) entirely in mineral form, as ammonium nitrogen (NH4-N) and nitrate nitrogen (NO3-N). Total N concentration is reported to vary in range of 13-20% N1. The high N concentration gives a potential for recovered AN to be used as a replacement for synthetic N fertilizers.

REFERENCE AGAINST WILL BE EVALUATED: Impacts from crop production with mineral fertilization.

1. Use of primary resources

This management solution is focused on the use and application of recovered ammonium nitrate as compared to synthetic mineral nitrogen fertilizer. Therefore, it is not clear if the impact on production should be taken into consideration or not.

Natural gas: More specifically, it is known that natural gas is used for production of synthetic N fertilizer. With production and use of recovered ammonium nitrate, the demand for synthetic N fertilizer would reduce and hence reduction in the use of natural gas would occur.

Oil: In this management solution, calcium ammonium nitrate is used as a synthetic N fertilizer, and it is present in granular form. The recovered ammonium nitrate is present in liquid form.

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This means that another type of machinery is needed for application of ammonium nitrate. Nevertheless, both products need machinery to be applied, and these machines need oil for the operation. Therefore, we assume there is no effect on oil consumption as compared to the reference scenario.

Nutrients recovered: Ammonium nitrate is a product with high N concentration, but also with high EC values. Sigurnjak et al. (2019) reported EC value ranging 332-342 mS/cm and N concentration of 13.2 -19.8%. Since ammonium nitrate has a high N concentration, a lower amount of product is needed to fulfil crop needs, and hence also lower amount of salts is applied on the field. In lettuce pot trial and one-year maize field trial by Sigurnjak et al. (2019), application of ammonium nitrate did not lead to an increase in EC levels of soil as compared to the use of synthetic N fertilizer, nor did it show any negative effects on the yield. Therefore, from this short-term experiment, it seems that ammonium nitrate had the same effect on soil quality as synthetic N fertilizer. However, it is not known what effect the product might have on soil quality in a longer term. The pH of product ranged 6.92 -7.85 (Sigurnjak et al., 2019). So, negative effect on soil quality in terms of pH is not expected. Finally, ammonium nitrate is 100% mineral N fertilizer. Total N is present in NH4-N and NO3-N form. Meaning, the fertilizer value of this product is 100%, as it is the case with synthetic N fertilizers.

2. Emissions to the environment

Nitrous oxide (air) and Methane (air): In Flanders, the location where this management solution will be tested, all liquid fertilizers need to be injected in order to reduce the potential risk of GHG emissions. Therefore, it is assumed that the effect on emissions into the air is none existing as compared to synthetic N fertilizers which are in practice surface applied. This, however, has not been measured directly in the field.

Nitrates (water): For potential risk on nitrate leaching, in study by Sigurnjak et al. (2019), no difference in risk of leaching has been observed between synthetic N fertilizer and ammonium sulphate.

Ammonia (air), Phosphorus (water), Particulate matter: No changes are expected.

3. Resilience to climate change

Carbon footprint: LCA was not conducted, but reduction in C footprint due to the substitution of synthetic mineral N fertilizers is expected.

Non-renewable energy consumption: On the other hand, production of ammonium nitrate via stripping/scrubbing technology requires electricity. The electricity usage in range of 1.5-12 kwh/t processed (Vaneeckhaute et al., 2017) and 0.8-28 kwh/kg N recovered (Tampio et al., 2016) have been reported in past studies. Of course, this also depends on the technological cascades that are implemented. Meaning, if anaerobic digestion (AD) is coupled to stripping/scrubbing (as it is the case for this management solution), then the used electricity is actually produced by AD plant.

Soil quality and Nutrients recovered: Ammonium nitrate is a product with high N concentration, but also with high EC values. Sigurnjak et al. (2019) reported EC value ranging 332-342 mS/cm and N concentration of 13.2 -19.8%. Since ammonium nitrate has a high N concentration, a lower amount of product is needed to fulfil crop needs, and hence also lower amount of salts is applied on the field. In lettuce pot trial and one-year maize field trial by Sigurnjak et al. (2019),

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application of ammonium nitrate did not lead to an increase in EC levels of soil as compared to the use of synthetic N fertilizer, nor did it show any negative effects on the yield. Therefore, from this short-term experiment, it seems that ammonium nitrate had the same effect on soil quality as synthetic N fertilizer. However, it is not known what effect the product might have on soil quality in a longer term. The pH of product ranged 6.92 -7.85 (Sigurnjak et al., 2019). So, negative effect on soil quality in terms of pH is not expected. Finally, ammonium nitrate is 100% mineral N fertilizer. Total N is present in NH4-N and NO3-N form. Meaning, the fertilizer value of this product is 100%, as it is the case with synthetic N fertilizers.

Renewable energy production: No changes are expected.

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RL4.LL2 Ammonium stripping / scrubbing and NH4SO4 as substitute for synthetic N fertilizers (UGhent/Inagro)

BRIEF DESCRIPTION OF THE TECHNOLOGY: The aim of ammonia (stripping-)scrubbing is to produce ammonium sulphate (AS) solution. AS contains total nitrogen (N) entirely in mineral form, as ammonium nitrogen (NH4-N). The total N concentration is reported to vary in range of 3-9% N. The high N concentration gives a potential for recovered AS to be used as a replacement for synthetic N fertilizers. Additionally, given the high sulphur content (3-11%), AS is also a valuable source of S1.

REFERENCE AGAINST WILL BE EVALUATED: Impacts from crop production with mineral fertilization.

1. Use of primary resources

This management solution is focused on the use and application of recovered ammonium sulphate as compared to synthetic mineral nitrogen fertilizer. Therefore, it is not clear if the impact on production should be taken into consideration or not.

Natural gas: More specifically, it is known that natural gas is used for production of synthetic N fertilizer. With production and use of recovered ammonium sulphate, the demand for synthetic N fertilizer would reduce and hence reduction in the use of natural gas would occur. On the other hand, production of ammonium sulphate requires electricity that is needed for ventilation system in pig stables. In Flanders, the region where this management solution will be tested, the expected electricity usage is 24kWh/animal place/j* = 5,04 euro/animal or for ±85kWh/sow

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place/j* = 17,85 euro/animal (Innovatiesteunpunt Boerenbond, 2016). Of course, this can also depend if anaerobic digestion (AD) is present at the pig farm, because then electricity is produced at the site.

Oil: In this management solution, calcium ammonium nitrate is used as a synthetic N fertilizer, and it is present in granular form. The recovered ammonium sulphate is present in liquid form. This means that another type of machinery is needed for application of ammonium sulphate. Nevertheless, both products need machinery to be applied, and these machines need oil for the operation. Therefore, we assume there is no effect on oil consumption as compared to the reference scenario.

Nutrients recovered: Finally, ammonium sulphate is 100% mineral N fertilizer. Total N is present in NH4-N form. Meaning, the fertilizer value of this product is 100%, as it is the case with synthetic N fertilizers. Also, the product contains S.

Rock phosphate and Water: No changes are expected.

2. Emissions to the environment

Nitrous oxide (air) and Methane (air): In Flanders, the location where this management solution will be tested, all liquid fertilizers need to be injected in order to reduce the potential risk of GHG emissions. Therefore, it is assumed that the effect on emissions into the air is none existing as compared to synthetic N fertilizers which are in practice surface applied. This, however, has not been measured directly in the field.

Nitrates (water): For potential risk on nitrate leaching, in study by Sigurnjak et al. (2019), no difference in risk of leaching has been observed between synthetic N fertilizer and ammonium sulphate.

Ammonia (air), Phosphorus (water), Particulate matter: No changes are expected.

3. Resilience to climate change

Carbon footprint: LCA was not conducted, but reduction in C footprint due to the substitution of synthetic mineral N fertilizers is expected.

Soil quality: Total N concentration, pH and EC value of ammonium sulphate ranged between 3-8.6%, 2.4-7.7 and 152-262 mS/cm, respectively, in study by Sigurnjak et al. (2019). Since ammonium sulphate has a lower N concentration than ammonium nitrate, higher amount of product is needed is needed to fulfil crop needs, and hence also more salts can be applied on the field. In lettuce pot trial and one-year maize field trial by Sigurnjak et al. (2019), application of ammonium sulphate led to significantly higher EC levels of soil as compared to the use of synthetic N fertilizer and recovered ammonium nitrate. Also, high levels of sulphur were detected in soil, but none of this has influenced the crop yield at the harvest time. The long-term studies on ammonium sulphate are not available, but it is expected that application of ammonium sulphate with acidic pH and high EC would reduce in time the quality of soil.

Non-renewable energy consumption and Renewable energy production: No changes are expected.

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RL4.LL6 Concentrate from vacuum evaporation/ stripping as nutrient-rich organic fertilizer (UGhent)

BRIEF DESCRIPTION OF THE TECHNOLOGY: The purpose of vacuum evaporation is to optimize nutrient recovery from waste stream and produce organic fertilizer with high content of nutrients in small volume. Anaerobic digestion plant Waterleau has installed an evaporator with the aim to reduce the water content of their liquid fraction (LF) of digestate and recover N in the form of ammonia water. The biogas plant is co-digestion of 45% manure and 55% biological waste streams, which is heated/mixed up to 40 °C and is digested for 30 days (+10 days in the post digester). The digestate is hygienized (1 hour at 70 °C) and separated by a centrifuge. The solid fraction is dried in a Hydrogone® dryer. This LF of the digestate (15m³/h) goes to a biological aerobic water treatment for small removal of COD. In the next step (evaporator) ammonium is transferred to the gas phase and a K rich solution is concentrated. The ammonia rich gas condenses with the water vapour and is recycled as ammonia water.

REFERENCE AGAINST WILL BE EVALUATED: To evaluate the nitrogen fertiliser replacement value (NFRV) of the concentrate from evaporation, three-year field-scale trials were designed on mono-cultivation of maize. The agronomy performance of the produced concentrate, together with the input pig manure, unseparated digestate, LF of digestate and ammonia water, was compared to the no-fertiliser and synthetic fertiliser (calcium ammonium nitrate (CAN)) treatments.

1. Use of primary resources

Nutrients recovered: Vacuum evaporation is a robust and proven technology that has an attractive potential to separate water and concentrate nutrients in waste streams, resulting in high-value green fertilisers with reduced volume (Chiumenti et al., 2013; Guercini et al., 2014). The produced concentrate contains 8,83 ± 0,07 g N kg-1 (91% in organic form), 5,48 ± 0,05 g P2O5 kg-1 and 21,80 ± 0,51 g K2O kg-1 on fresh weight (FW) basis. In this field trial, according to the soil N test and maize N demand, all fertilisers including the concentrate were applied at 105 kg N ha-1. The application rates of total P and total K were compensated by triple superphosphate (TSP, 40% P2O5) and potassium chloride (60% KCl) to the highest supplies as 65 kg P2O5 ha-1 and 259 kg K2O ha-1 in the concentrate treatment. Therefore, the concentrate can be used as an organic NPK compound fertiliser and has the potential to replace synthetic fertilisers in agriculture.

Rock phosphate and Natural gas: The partly or fully substitution of synthetic fertilisers by this concentrate can help reduce the consumption of rock phosphate and natural gas for production of P and N fertilisers. Normally the concentrate from evaporation process is blended with digestate or other derivatives such as solid fraction of digestate. To the best of our knowledge,

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this on-going field trial is the only one that evaluates the fully substitution of synthetic fertiliser by this concentrate as a single fertiliser. Thus, there is no published result available as reference for this research.

Water: As no irrigation was conducted during the maize growing season, there is no directly impact on water usage in field application of the concentrate.

Oil: No changes are expected.

2. Emissions to the environment

During the agricultural application, there are many pathways for nutrients loss into environment, including gaseous emission (NH3, N2O, NOx, CH4) and leaching (nitrate, ortho-P). It was estimated by Leip et al. (2014) that the global N loss from agricultural via nitrate leaching, denitrification (conversion to N2 gas) and ammonia emissions can count for 43%, 30% and 23%, respectively.

Ammonia (air) and Particulate matter: In the case of the concentrate from Waterleau evaporation process, due to the low NH4+-N proportion (9% of total N), we assumed there should be no significant difference in NH3 emission compared to synthetic fertiliser. Also, particulate matter is not affected.

Nitrous oxide (air): However, the high organic nitrogen content in the concentrate may lead to higher denitrification and thus higher N2O emission.

Referring to P loss, compared to the 100% of available P in CAN treatment, the P in the Waterleau concentrate was estimated to be associated to the organic matters (He et al., 2009) and thus showed lower direct availability but also lower leaching risk.

Nitrates (water): We assume there is no significant difference in nitrate leaching between mineral fertilization and application of concentrated digestate.

Methane (air): No changes are expected in this indicator.

3. Resilience to climate change

Carbon footprint: The Waterleau anaerobic digestion + evaporation process reduces the overall greenhouse gas (GHG) emission by reconnecting the livestock husbandry and crop production.

Non-renewable energy consumption: In Waterleau plant, the biogas produced from anaerobic digestion process can be used to produce electricity and thus save the energy consumption in later separation and evaporation process.

Soil quality: Addition to nutrients like NPK, the application of the concentrate also provides 54,8 ± 0,0 g kg-1 FW of organic carbon (OC), which can be utilised by soil microorganisms and improve the soil quality (Oldfield et al., 2019).

Renewable energy production: The production of biogas and high value fertilisers help to close the CNP loops and contributes to a more sustainable agriculture.

Reference

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RL4.LL9 Liquid fraction of digestate as a substitute for mineral N & K fertilizer (UGhent/Inagro)

BRIEF DESCRIPTION OF THE TECHNOLOGY: Solid-Liquid separation is the most frequent first step in digestate processing and is usually carried out on-site to reduce transportation costs for disposal, to free up storage space or for further upgrading (such as nutrient extraction). The phase separation leads to a P-rich solid fraction (SF) and a N and K-rich liquid fraction (LF). The SF contains high phosphorous and organic fractions, which is interesting for soil properties and humus formation. It can be further dried, composted, granulated or directly applied to the field as soil amendment. The LF, with high contents of plant-available N and K, is more suitable as a fertiliser applied via soil mixing (slurry cultivator), mechanical injection, drag hoses or surface dressing.

REFERENCE AGAINST WILL BE EVALUATED: Crop production with mineral fertilization.

1. Use of primary resources

Nutrients recovered: In study by Sigurnjak et al. (2017), the NPK concentration of tested LF of digestate ranged to 3.6-7.2 g N/kg, 0.027-1.6 g P/kg and 2.2-3.7 g K/kg. Therefore, LF of digestate is considered as P-poor and NK-rich product. By producing LF of digestate there is potential to recover NPK and C.

Rock phosphate: Even though LF of digestate is considered as a P-poor fertilizer, the P concentration in the product still can lead to the reduction of using P from synthetic fertilizers. This is observed on field level, and therefore we assigned the small effect on use of rock phosphate for this solution.

Natural gas: As a N rich product, the use of LF of digestate would lead to reduction of using synthetic N fertilizer and hence the reduction in natural gas.

Oil: In this management solution, calcium ammonium nitrate is used as a synthetic N fertilizer, and it is present in granular form. The recovered LF of digestate is present in liquid form. This means that another type of machinery is needed for application of LF of digestate. Nevertheless, both products need machinery to be applied, and these machines need oil for the operation.

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Therefore, we assume there is no effect on oil consumption as compared to the reference scenario.

Water: Depending on the efficiency of mechanical separation and the use of polymers to up-concentrate P in solid fraction of digestate, the dry mater content of LF of digestate can range from 2-9% dry matter. This means that the rest is water. However, in this longlist solution the LF of digestate is applied in field settings and here irrigation is not needed. So, there is no effect on water increase or reduction. Maybe in greenhouse settings there might be an effect of water reduction, but not in the case of field setting.

2. Emissions to the environment

Ammonia (air), Nitrous oxide (air), Methane (air) and Particulate matter: In Flanders, the location where this management solution will be tested, all liquid fertilizers need to be injected in order to reduce the potential risk of GHG emissions. Therefore, it is assumed that the effect on emissions into the air is none existing as compared to synthetic N fertilizers which are in practice surface applied. This, however, has not been measured directly in the field.

Nitrates (water): For potential risk on nitrate leaching, in study by Sigurnjak et al. (2017), no difference in risk of leaching has been observed between synthetic N fertilizer and LF of digestate.

Phosphorus (water): LF digestate contains low concentration of P (as most of it is in solid fraction of digestate), so it is expected to have no effect on P water emissions.

3. Resilience to climate change

Carbon footprint: LCA was not conducted, but reduction in C footprint due to the substitution of synthetic mineral N fertilizers is expected.

Non-renewable energy consumption: No changes are expected in energy consumption.

Soil quality: Since the product has a low dry matter content, in practice it is not really considered as a rich source of C. However, recent study by Tambone et al. (2019) states that LF of digestate contains large amount of organic carbon that is biologically stable, and as such can act as organic amendment contributing to soil OC balance. Therefore, according to the authors the good amendment properties of LF of digestate cannot be ignored, contrary to the common opinion. It is important to highlight that the study by Tambone et al. (2019) focused on assessment of 11 LF of digestate obtained from screw press.

Renewable energy production: No changes are expected.

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RL5.LL62 Blending of raw and treated organic materials to produce organic fertilisers (NPC) (ISA)

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

BRIEF DESCRIPTION OF THE TECHNOLOGY: The proposed solution aimed at producing bio-based fertilisers by blending raw or treated manures with a known ratio of N:P:K, to enhance the proper use of manures as organic fertilisers and reduce the use of mineral fertilisers.

REFERENCE AGAINST WILL BE EVALUATED: In the present study, we compare the use of blending relative to raw materials (treated and untreated manure) and mineral fertilisers.

1. Use of primary resources

Natural gas: By using organic fertilisers obtained through the blending of raw and treated manure, the necessity of applying mineral fertilizers will decrease over time. Furthermore, a decrease of mineral fertilizers application to soil will impact the amounts produced and consequently decrease the amount of gas consumption used for fertilizers production.

Rock phosphate: Contributes to restore some of the nutrients natural soil reserve, namely phosphorous. Also, by improving SOM, the soil water retention capacity will improve (Hinsinger, 2014).

Water: Nonetheless, manures such as slurry have a high water content, which is counted as water supply and thereby the irrigation will account this factor.

Nutrients recovered: Each treatment applied to the slurry have a clear objective and improves nutrient recovery in a specific way, while improving the manure fertilizer value (Fangueiro et al., 2011).

Oil: Oil is evaluated as machinery use, therefore, Not impacted by the technology compared to the baseline.

Emissions to the environment

Ammonia (air): Treatment applied to the manure should decrease NH3 emissions relative to the application of raw manure and in some specific cases decrease it to levels compared with mineral fertilisers (e.g. Slurry acidification).

Nitrous dioxide (air) and Methane (air): The same trend should be observed for GHG in particular for nitrogen dioxide. (Dennehy et al., 2017; Loyon et al., 2007; Prado et al., 2020).

Nitrates (water): Relative to the potential of nitrate leaching it is expected that depending on the treatment performed to manure, the nitrates leaching can be reduce even during winter period (e.g. with acidification) (Cameira et al., 2019).

Phosphorus (water): The slurry acidification turns phosphorus more soluble reason why P can become more susceptible to be leach (Cavanagh et al., 2011).

Particulate matter: Not evaluated.

2. Resilience to climate change

Carbon footprint: Adding a material rich in carbon to soil will contribute to close the C cycle and also reduces the carbon footprint associated to the use mineral fertilisers (Krause and Rotter, 2018).

Non-renewable energy consumption: However, due to some of the treatments that can be applied to manure, such as the solid-liquid separation, it may increase the use of electricity.

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Soil quality: Since it is an organic material, a fertilization plan based on manure should increase soil quality due to the input of carbon to the soil (and thereby soil organic matter content-SOM).

Renewable energy production: Not impacted by the technology.

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RL5.LL47 Production of growing substrates for horticulture application from poultry manure, solid state digestate and biochar through composting (PCZ)

BRIEF DESCRIPTION OF THE TECHNOLOGY: Within this research line the overall goal is to convert poultry manure and/or solid state digestate mixed with bulking agents and biochars into growing substrates.

REFERENCE AGAINST WILL BE EVALUATED: This will be evaluated against the way unprocessed poultry manure is generally managed, i.e., by field spreading of unprocessed poultry manure (Dróżdż et al., 2020).

1. Use of primary resources

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Rock phosphate: Composting of poultry manure with the addition of selected substrates contributes to the increase in phosphorous recovery. It is anticipated that this will result in lower use of rock phosphate as poultry manure compost can function as a soil improver due to e.g. phosphorous content.

Natural gas: Production of alternative growing substrates and/or soil improvers through composting requires less energy input than production of conventional chemicals. Composting does not require complicated technology compared to the production line of e.g. mineral fertilizers. We can distinguish two types of composting, one in laboratory reactors (this solution is used in the project N2C) and composting in a heap in the outdoor (this method can be used by anyone who produces kitchen and agricultural waste, etc.). When it comes to composting in reactors, we can buy ready-made reactors or build them ourselves. It is a one-time cost and the use of the reactors many times. For the project, the composting reactors were made generally available materials, i.e. plastic barrels, insulation material, plastic hoses and aeration pumps (e.g. for swimming pools) etc. Therefore, one of the most cost-efficient solutions is composting of poultry manure with other agricultural residues in a composting reactor or windows. The advantages of composting are numerous. This is a common method for managing organic by-products, due to low production costs, social acceptance, simple technology and products that are a rich source of micro and macro elements (Foged et al., 2011).

Water: Adding biochar as a supplementary material to poultry manure composting mixture could retain water during the process. The developed biochar-added compost applied to soil in the longer perspective will allow water to be retained in soil.

Nutrients recovered: Poultry manure management through composting allows recovery of N, P and C. Poultry manure is a valuable substrate for fertilizing plants because it has a high concentration of nutrients (CNP). It is rich in nitrogen compounds that are essential for the growth of plants, e.g. for legumes. Fresh poultry manure substrate, depending on the type of poultry rearing, season, breed and production group may contain a number of valuable nutrients. For example, poultry manure contains about 1.2-2.3% nitrogen, 0.5-0.7% phosphorus and 0.4-0.6% potassium. Nitrogen in poultry manure occurs, among others in the form of uric acid, urea, ammonium and nitrogen of the feed protein, ammonia (Dróżdż et al., 2020).

The addition of poultry manure-derived biochar in composting will result in obtaining a compost richer in micro and macro elements. Also, it will enrich the soil with organic matter and enhancer soil porosity. Due to biochar sorption properties, it will also have a positive effect on the retention of moisture in the soil. Biochar can influence to reduce ammonia emission (Janczak et al., 2017).

Oil: Oil is evaluated as the oil used in agricultural machinery; therefore, no changes is expected in the technology.

2. Emissions to the environment

Ammonia (air) and Methane (air): Mature poultry manure compost, unlike fresh poultry manure that ends up in farmland, is devoid of smell, odors, and does not release large amounts of gases, i.e. ammonia. It is also microbiologically stable and, if it's fulfills the requirements for composts, poses no threat to the environment. Storage of poultry manure can generate odors and gaseous emissions such as ammonia and methane. It is estimated that the total amount of nitrogen released from chicken manure in the form of ammonia is 2–20% from laying hens and 13–20%

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from broilers. As for methane emission from 1000 birds, it is generally estimated at 80 kg per year (Mielcarek, 2012). Converting excessive quantities of poultry manure trough composting could reduce the emission of ammonia and methane from uncontrolled storage on site. However, still the most common challenge for poultry manure composting which is nitrogen loss through ammonia emission which can range from 13 to 70% (Hao and Benke, 2008; Shin et al., 2019). In addition, using biochar in composting of poultry manure (high N content of about 4%) allows reduction of ammonia emission during composting (Janczak et al., 2017).

Nitrous oxide (air), Nitrate (water), Phosphorus (water) and Particulate Matter: These indicators were not evaluated by the technology.

3. Resilience to climate change

Carbon footprint: Energy and CH4 emissions are saved using the technology, contributing to decrease carbon footprint.

Non-renewable energy consumption: However, obtaining biochar through pyrolysis of poultry manure requires energy input, depending on the process parameters and installations.

Soil quality: The obtained growing substrates and/or soil improvers will significantly improve soil properties.

Renewable energy production: During composting in an industrial scale, the heat generated during the process can be used for heating water in a composting facility.

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RL6.LL65 Struvite as a substitute of synthetic P fertilizer (UGent)

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Phosphate rock is the sedimentary rock, raw finite material, that can be used directly as a fertilizer or transformed into other commercial mineral P fertilizers. The majority of global phosphate rock reserves are located in Morocco, as well as in Iraq, China, Algeria, Syria, Jordan, South Africa, the US, and Russia (De Ridder et al., 2012). Recently, with the addition of the phosphate rock and white phosphorus (P4) to the list of critical raw materials, the search for alternative P resources emerged (EC, 2014, EC, 2017). Municipal wastewater and sewage Sludge obtained at the end of the municipal wastewater treatment (MWWT) have been identified as a relevant P source (van Dijk et al., 2016). The quality of phosphate rock may significantly vary and is often contaminated with pollutants such as the heavy metals cadmium and uranium (De Ridder et al., 2012). The direct use of sewage Sludge, however, is the most efficient option in terms of energy and overall emissions of greenhouse gases, but its big drawback is the tendency to impose the soil and thus environment contamination as having high heavy metal and emerging organic pollutant content (Linderholm et al., 2012). On contrary to those two, the struvites have proved to be the highly pure fertilizers, having even fewer or no contaminants than the commonly used phosphorus fertilizers processed from P rock (Britton, 2007; Huygens et al., 2019).

BRIEF DESCRIPTION OF THE TECHNOLOGY: Placement of phosphorus (P) to the list of critical raw materials1 created clear demand for P recovery technologies which would allow for production and utilization of phosphorus in more sustainable manner. The most common solution for P recovery is phosphorus precipitation in form of struvite. Struvite will come from sludge and struvite from liquor.

REFERENCE AGAINST WILL BE EVALUATED: Crop production with mineral fertilization.

1. Use of Primary Resources

Rock phosphate: This further led to creation, the struvite precipitation, one of the most common P recovery technologies that process municipal sewage Sludge into valuable agronomical fertilizers was created (Sartorius et al., 2011, Bogdan et al., 2020). Struvite is the P salt which besides the phosphorus also contains significant amounts of nitrogen and magnesium.

Nutrients recovered: The advantage of the struvite P recovery technology is that it can be installed next to the municipal wastewater treatment plant, enabling the direct availability of the P fertilizer on the local market, and eventually leading to a reduction of the EU's dependency on the rock P imports.

Oil: Of course, further transporting of the struvites may significantly increase the net environmental impact.

Natural gas, Oil, Water: No changes are expected.

2. Emissions to the environment

The LCA results on P recovered fertilizers differ significantly based on their settings (from the aspect of the WWTP configuration, sludge categorization as waste or product, up to uniqueness of each P recovery technology and use of various reference materials as a comparison to struvites) and thus the environmental impact of P precipitation can be found in one study evaluated as positive and in other as negative ((Bradford-Hartke et al., 2015), (Pradel and

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Aissani, 2019). Special attention in LCA's should be paid to the varieties of the P recovery process into struvite: directly from sludge (often not pure struvite), from urine, from centrate (the most common), after chemical or biological leaching of the Sludge. Moreover, the equipment used can also contribute significantly to the outcome of the life cycle cost and global warming. Thus, generalization without standardization in this respect is quite impossible, being all emissions considered as unknown.

3. Resilience to climate change

Carbon footprint: Positive.

Non-renewable energy consumption and Renewable energy production: No changes are expected.

Additional material

For example, in one recent study, the production of a PO4-enriched stream from Sludge via elutriation in the primary thickeners was compared to WASSTRIP® process and its PO4-enriched stream mechanically obtained with dynamic thickeners. They found that the first process had a 23.0% lower life cycle cost and a 14.2% lower global warming impact per hm3 of treated influent than the second, while it also had by 17.6% less the total annual equivalent cost (TAEC) and 2.0% less global warming impact compared to the reference.

The specific cost influence per amount of phosphorus recovered with precipitation processes ranges from negative up to 230% of current market prices for phosphorus from triple-superphosphate (TSP).https://scihub.wikicn.top/https://doi.org/10.2166/wst.2017.212 the influence of phosphorus recovery in form of P precipitation on the overall cost of the wastewater and Sludge treatment trains is identical to the process costs of Sludge disposal as the Sludge disposal pathway is not affected by these recovery options.

"Results indicated that Sludge-based phosphate fertilizers appeared less environmentally friendly than mineral phosphate fertilizers, due to the contribution of the upstream burden of Sludge production and P recovery. Finally, although P recovery helps preserve the mineral P resource, the overall assessment remains unfavorable for Sludge-based products due to the low yields of P recovery, low P concentration of the Sludge and the large amounts of energy and reactants needed to recover the P." https://hal.archives-ouvertes.fr/hal-02359904/document

"One unsolved question remains the overall environmental impacts of recovering this dissipated P compared to extracting phosphate from rocks. Some studies have assessed the environmental impacts of Sludge used as phosphate fertilizer using Life Cycle Assessment (LCA) (Sena and Hicks, 2018). Johansson et al. (2008) and Linderholm et al. (2012) compared four alternative options for handling Sludge, with the use of its P as fertilizer on agricultural soils. Bradford-Hartke et al. (2015) compared environmental benefits and burdens of recovering P as struvite from dewatering return liquors in four centralized and two decentralized systems.

In these comparative LCAs, recovering P from Sludge was seen more as an alternative waste treatment than as Sludge-based fertilizer production; thus, Sludge was considered to have no environmental burdens. In this context, using supercritical water oxidation to recover P appeared to be the best option for Johansson et al. (2008).

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For Bradford-Hartke et al. (2015), recovering P using struvite precipitation resulted in positive environmental impacts due to energy and chemical use being offset by operational savings and avoided fertilizer production."

"Ozone depletion models do not typically include N2O emissions, though emissions may occur from wastewater treatment,113−115 landfill of biosolids,116 and biosolids use in agriculture. We found the net ozone depletion potential was dominated by direct N2O emissions in four of the six case studies, and exclusion of N2O emissions from ozone depletion models could substantially alter the results https://scihub.wikicn.top/https://doi.org/10.1021/es505102v

"Notwithstanding the economic and resource recovery case,21 the literature contains conflicting data on overall environmental impacts of alternative recovery processes. For example, one study found that phosphorus recovered as struvite from solids dewatering streams was less energy intensive than chemical (FeSO4) removal by a factor of 2.3 and a factor of 1.4−1.7 lower than fertilizer production.22 Conversely, another study found struvite precipitation was more energy intensive than mineral fertilizer production by a factor of 2 and a factor of 10 greater than applying Sludge to land.23 Including the impacts of soil metal toxicity further highlights the difficulties when comparing processes. https://scihub.wikicn.top/https://doi.org/10.1021/es505102v

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RL6.LL49 Nitrogen and phosphorus recovery from pig manure via struvite crystallization and design of struvite based tailor-made fertilizers (CARTIF)

BRIEF DESCRIPTION OF THE TECHNOLOGY: The crystallization of nitrogen and phosphorus in the form of magnesium ammonium phosphate hexahydrate ($MgNH4PO4·6H2O$) also known as MAP or struvite, is one of the possible techniques used to eliminate and/or recover nutrients from the digestate, obtaining a product that can be applicable as a base in ecological fertilizers of high quality. In addition, the recovery of phosphate and ammonium in the form of struvite allows, in turn, the sustainable management of a non-renewable natural resource, phosphate, and the improvement of the quality of aquatic ecosystems.

REFERENCE AGAINST WILL BE EVALUATED: Crop production with mineral fertilisation

1. Use of primary resources

Nutrients recovered: Crystallization of N and P in the form of magnesium ammonium phosphate ($MgNH4PO4·6H2O$), also known as MAP or struvite, is one of the possible techniques used to eliminate and/or recover nutrients from the digestate, obtaining a product that can be applied as a base for high quality organic fertilizers. Depending on the technology used, up to 40% of N and 90% of P can be recovered from the effluent (Val del Río et al., 2016).

Rock phosphate: In addition, the recovery of phosphate and ammonium in the form of struvite allows, in turn, the sustainable management of a non-renewable natural resource, phosphate, and the improvement of the quality of aquatic ecosystems (Le Corre et al., 2009).

Water: Organic fertilizers have a high content of water, which saves water for irrigation.

Natural gas: The production of mineral fertilizer (natural gas consumption) is avoided when manure is valorized.

Oil: Oil is evaluated as oil used in agricultural machinery; therefore, it is unimpacted by the technology.

2. Emissions to the environment

Nitrates (water) and Phosphorus (water): In accordance with Rahman et al. (2011), in struvite-treated soil, N leaching losses are significantly different compared to soil treated with chemical fertilizers; therefore, in struvite-treated soil, N remains stored for longer and the plant will capture nutrients as needed. The latter is the main virtue of slow-release fertilizers (such as struvite) and, apart from the low losses due to N leaching, it is also related to the low solubility of struvite in water (0.018 g/100 mL at 25 ºC, Le Corre et al. (2009)). In line with several authors (Johnston & Richards, 2003; Rahman et. al., 2011), due to its solubility, struvite can be an effective fertilizer for acid soil and even obtains reasonable efficacies in soils with slightly basic pH (Massey et. al., 2009), not being recommended, however, for calcareous soils. Therefore, struvite can be an effective alternative source of P fertilization in a wide range of soil environments.

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Ammonia (air) and Methane (air): Finally, obtaining struvite avoids ammonia and methane emissions that would be generated by storage and direct use as a digestate fertilizer.

Particulate matter: This indicator was not assessed by the technology.

Nitrous oxide (air): Treating manure it is avoided nitrous oxide emissions.

3. Resilience to climate change

Carbon footprint: According to Britton et al. (2007), the struvite production from digestate results in reductions of over 50% in sulphur dioxide, carbon monoxide and nitrous oxide emissions and 80% lower greenhouse gas (GHG) emissions on a carbon dioxide equivalent (CO2eq) basis than traditional fertilizer manufacture.

Non-renewable energy consumption: The process of obtaining struvite is much less energy intensive than the process of obtaining traditional fertilizers. However, the production of struvite requires a significant amount of reagents consumption (i.e. magnesium salt and sodium hydroxide). This results from the fact that conventional fertilizer manufacturing processes are energy intensive, involving mining, long transport distances, thermal processes, and, in some cases, direct combustion of fossil fuels for product manufacture (e.g. urea production).

Soil quality: The organic matter (C) is not considered to be harmful for the fertilizing action of the struvite, but on the contrary, it will serve as a nutrient for the plant.

Renewable energy production: The struvite recovery facility operates under moderate power consumption, and usually uses waste heat from biogas combustion for product drying. However, this energy is not provided by the technology.

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RL6.LL52 Pilot-scale crystallizer for P recovery (UMIL)

BRIEF DESCRIPTION OF THE TECHNOLOGY: The solution consists in an air lift crystallizer which will be used to promote struvite crystallization in the liquid fraction of digestate.

REFERENCE AGAINST WILL BE EVALUATED: The struvite recovered will be tested on green rocket (Brassica rapa chinensis) in a pot scale experiment using chemical fertilizer as control test.

1. Use of Primary Resources

Phosphorus (P) and Nitrogen (N) based fertilizers production is expected to reach 201.66 million tonnes by the end of 2020. P pollution problem runs alongside the rising demand for phosphatic mineral fertilizers. Phosphorus is obtained from phosphate rocks, a limited and non-renewable source which is going to decrease from 2050 onwards (FAO, 2019; Zangarini et al., 2020). These are alarming data, considering not only the steady increase fertilizers demand but also the potentially pollutant nature of nitrogen and phosphorus (FAO, 2019). Struvite crystallization contains also ammonia (1:1 mole ration NH4 : P) and can be used to recover N as well as P (Çelen & Türker, 2001) which can be used as double nutrient fertilizer.

Rock phosphate and Nutrients recovered: Air lift-struvite crystallization can promote the high phosphorus removal (>95%) (Zangarini et al., 2020), even when combined with the use of seawater bittern (a by-product of sea salt processing) instead of magnesium chloride pure salt as the magnesium source (Pepè Sciarria et al., 2019). Moreover, the crystallizer technology used for struvite precipitation has already been tested in wastewater treatment plants and data reported in literature showed the feasibility of this technology for use with high total solids (>5%) livestock manure (Zangarini et al., 2020).

Oil: Dealing with oil, the solution itself does not cause appreciable differences with a traditional chemical fertilization.

Natural gas: The prototype though, works with anaerobic digestion and can make the process more feasible and more environmentally safe so to increase AD diffusion and saving natural gas and electricity.

Water: Water is not impacted by the technology.

2. Emissions to the environment

Ammonia (air): Because crystallization is an aerobic process and need a continuous flux of air in the liquid fraction, some ammonia volatilization will occur.

Nitrous oxide (air) and Methane (air): Dealing with N2O and CH4 emissions no differences are expected with chemical fertilization.

Nitrates (water) and Phosphorus (water): Recovering P from livestock effluents or digestate represent the resolution to respond both to the forthcoming collapse of the fertilizer's supply and to the rising of environmental problems linked to livestock effluents management such as eutrophication. Being struvite a slow-releasing fertilizer containing both P and N, it reduces leaching of both these nutrients. Struvite have been efficiently reported to be a slow release fertilizer able to replace mineral fertilizers (Daneshgar et al., 2018; Zangarini et al., 2020).

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Particulate matter: Ammonia is one of the most important source of particulate (PM2.5) (Behera & Sharma, 2010; Sharma et al., 2007), so due to this potential leak of ammonia this can provoke particulate matter formation, but it is not investigated by the technology.

3. Resilience to climate change

Carbon footprint: Struvite crystallization from digestate can allow to integrate this technology with anaerobic digestion plants within a double system process where AD can promote also renewable energies production improving carbon footprint reduction.

Non-renewable energy consumption: The prototype though, works with anaerobic digestion and can make the process more feasible and more environmentally safe so to increase AD diffusion and saving natural gas and electricity.

Soil quality: Soil quality is expected to be improved since leaching and erosion will be decreased using organic fertilizers.

Renewable energy production: This way biomasses are greatly valorized. AD recover biogas and energy, solid fraction can be composted and used as soil improver and finally, liquid fraction undergoes a recovery of nutrient before being used in field for fertilization/irrigation.

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RL7.LL23 Pig manure refinery into energy (biogas) and fertiliser using a combination of techniques applicable at industrial pig farms (UMIL)

BRIEF DESCRIPTION OF THE TECHNOLOGY: Different separations (a screw press, vibrating screens, and three steps reverse osmosis) will separate swine effluent in a solid fraction, a liquid concentrate, clean water and ammonium sulphate. These products will be tested on corn crop in a full field experiment.

REFERENCE AGAINST WILL BE EVALUATED: A non-fertilized plot and one fertilized with untreated swine effluent will be tested as control test.

N.B. The plant started running early September 2020, no data is available yet. Therefore, all information reported hereinafter is a result of literature review or information collected from the sub-contractor.

1. Use of Primary resources

Rock phosphate: Phosphorus is an essential nutrient in agriculture, and being a non-renewable resource (and furthermore scarcely present in European underground) recovering it from waste biomass is of extremely importance (Zangarini, Pepè Sciarria, Tambone, & Adani, 2020). Since the concentrate produced by separation is rich in P, it completely fulfils crop needs for this element, so that no rock phosphate is needed.

Natural gas and oil consumption: Have any significant difference.

Water: Another advantage of this technology is that it helps saving water. The technology separates clean water from the effluent as reported in other studies (Ledda, Schievano, Salati, & Adani, 2013; Utomo, Yu, Zhi Yi, & Jun, 2017)(Cath et al., 2005). The plant chosen for this study will recover up to 60% of clean water. It is worth to mention that during traditional exploitation of livestock effluent no clean water is recovered.

Nutrients recovered: The concentrate recovered from the liquid fraction will be rich in minerals, especially N and P, according to sub-contractor preview. Normally N concentration vary around 8,5 g/kg (75% of input N) of which about 90% is in ammonia form and P content will vary around 1.5 g/kg. Since the concentrate will consist in about 15% of the input volume, it is easy to understand how this solution can greatly increase the facility of nutrient management.

2. Emissions to the environment

Ammonia (air), Nitrous oxide (air), Methane (air): Stocking of swine livestock effluent is known to cause consistent emission of greenhouse gasses and ammonia (Husted, 1994). The proposed solution aims to greatly reduce emissions since effluent will be treated immediately and stocked as separate fractions. The plant will work constantly ,360 days/year to avoid accumulation of sludge.

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Nitrates (water) and Phosphorus (water): N and P emission by water leaching and run off are more difficult to assess, though an easier management of biomass and nutrients is expected to lead to lesser losses of nutrient, hopefully interesting results will be provided about this topic.

Particulate matter: Ammonia is well known to form particulate suspension (PM2.5) (Behera & Sharma, 2010; Sharma, Kishore, Tripathi, & Behera, 2007). We estimate that a reduction of ammonia emission can positively influence the formation of particulate emission.

3. Resilience to climate change

Carbon footprint and Effective SOM: Increase organic matter in soil has a great impact on soil quality and helps as well stocking C and reducing the emission of CO_2 in atmosphere (Janzen, 2004; Merino, Pérez-Batallón, & Macías, 2004). Solid fraction contains high quantity of organic matter, and can be exploited as such or after composting and/or pelleting, in order to increase recalcitrance of carbon compounds (Brito, Coutinho, & Smith, 2008; Pampuro et al., 2017; Tambone, Terruzzi, Scaglia, & Adani, 2015). We expect that the positive effect of C stock will overcome the modest energy consumption required by the plant. A Life Cycle Assessment on Carbon Footprint will be performed for this solution to confirm or refute our expectation.

Non-renewable energy consumption: A small amount of electric energy will be required for the separation process (Gude, 2012). A rough estimation made by the sub-contractor set a consumption of about 30 KWh/day for treating 100 m^3 day^{-1} of input volume.

Soil quality: Organic matter is a pivotal point of soil quality, and the use of amendments is very important in modern agriculture (Magdoff & Weil, 2004). After solid/liquid separation only a small fraction of the N and P is found in the solid fraction (13% and 29% respectively) (Tambone, Orzi, D'Imporzano, & Adani, 2017). This will allow to use a larger quantity of solid fraction in order to obtain a higher organic matter content in the soil taking into account the legal limits for N and avoiding an excessive P load.

Renewable energy production: Manure from pig farms is treated by a process of Anaerobic Digestion, which recovers energy in form of biogas.

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RL7.LL20. Low temperature ammonium-stripping using vacuum (IRTA)

BRIEF DESCRIPTION TECHNOLOGY: Livestock manure is typically applied to cropland when it is generated in an amount that fits the farm's land nutrient needs. But when it is produced in excess, livestock manure will need correct management and/or treatment due to its high organic matter content and concentration of nutrients, especially phosphorus and nitrogen. Unlike ammonia removal, ammonia recovery can produce marketable products, such as fertilizers.

Low temperature vacuum evaporation can be applied to recover ammonia from livestock manure, to obtain a salt that can be used as fertilizer. When vacuum is applied to an enclosed reactor, boiling point temperature decreases to below normal boiling point, thus reducing energy cost as a result of lower heating requirement. In addition, gas-phase ammonia mass

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transfer is boosted by suction effect of the applied vacuum. Thanks to the low pressure and a pH basification, ammonium-ammonia equilibrium is displaced to the second species and easily evaporated at a relatively low temperature (40-45 °C). The evaporated ammonia is absorbed in an acid solution, and can be in the form of an ammonium sulfate, nitrate or lactate salt solution, among others. On the other hand, a treated Slurry stream will be obtained, with a lower ammonia content, that could be applied to soil.

This technology can be applied directly to raw livestock manure, in order to avoid ammonia gas emissions to the atmosphere, or as a subsequent step of an anaerobic digestion process.

REFERENCE AGAINST WILL BE AVALUATED: The reference will be pig manure management without processing in Spain, where surplus livestock manure is exported to distant croplands.

1. Use of Primary Resources

Rock phosphate and Natural gas: The use of pig manure and recovered ammonia will replace the use of mineral fertilizers (Tao et al., 2018), with consequent reduction of rock phosphate and natural gas used in their manufacture. It has been reported that fertilizer sector consumed approximately 35% of natural gas in 2001 (Quader, 2003). The treated livestock manure, which will retain the phosphorus, can be applied near to the farm, instead of being exported, since N restrictions will be reduced.

Oil: No impacts are expected for this indicator.

Nutrients recovered: The valorization of manure as fertilizer means a recovering of nutrients (Tao el al., 2018). Expecting more than 60% ammonia recovery from livestock manure, it would represent a 13 tn/year saving of N mineral fertilizer production (assuming a 1200 sow farm with a livestock manure production of 18 m3/d and 2000 mg N/L).

Water: This technology does not involve neither increase nor reduction of water needs.

2. Emissions to the environment

Ammonia (air): Livestock manure storage in pits is a known source of ammonia emissions to atmosphere (Kupper et al., 2020). Treatment of this manure, N recovery and use as fertilizer in non-volatile form will mean a decrease of ammonia emissions.

Nitrous oxide (air) and Methane (air): Regarding dinitrogen oxide and methane emissions, it results neutral.

Nitrates (water) and Phosphorus (water): The recovery of N and P and reuse as fertilizer has the potential to reduce the loss of nitrates and phosphates to zero.

Particulate matter: No effects on particulate matter emissions.

3. Resilience to climate change

Carbon footprint: The substitution of mineral fertilizers will contribute to reduce the carbon footprint, due to CO_2 emissions reduction of mineral fertilizer production. Livestock manure processing on farm and ammonia reduction of the treated fraction will allow for local soil application, instead of exportation. On the other hand, the N concentrated solution may be exported.

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Non-renewable energy consumption: Vacuum stripping needs an energy input for pumps operation and heating (Tao et al., 2018). Ukwuani and Tao (2016) reported that vacuum thermal stripping will require only 2107 kWh/d energy to heat 66.6 m3/d of digestate from 37 °C to 65 °C plus approximately 39 kWh/d energy to power vacuum pumps, thus incorporating vacuum can decrease energy demand by 56% with respect to traditional thermal ammonia stripping.

Soil quality: It is expected an increase of soil quality because of the addition of organic matter if the treated fraction is applied to the soil (Yagüe et al, 2016).

Renewable energy production: No changes in renewable energy production are anticipated.

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RL7.LL55 Manure processing and replacing mineral fertilizers in the Achterhoek region (WUR)

BRIEF DESCRIPTION OF THE TECHNOLOGY: Through processing the regional manure surplus is refined into different biobased fertiliser products, instead of being exported outside the Netherlands.

REFERENCE AGAINST WILL BE EVALUATED: For this solution the NK concentrate product is used to replace mineral N fertilisers on grassland in the region.

1. Use of primary resources

Natural gas and Nutrients recovered: Through the processing of manure, the NK concentrate is considered as mineral fertilizer instead of animal manure. This means that mineral fertilizer application can be replaced. The process of N fertilizer production is very energy intensive, therefore natural gas can be saved.

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Oil: The positive evaluation for oil for LL55 was based on the reduction of transport of manure, as it will be treated now in the Netherlands instead of being exported, and the treated products that are not used locally are much lower in volume.

Rock phosphate, and Water: No changes are expected.

2. Emissions to the environment

Ammonia (air): As the NK concentrate has a high NH4 content, there is risk on increased NH3 emissions. However, with injection this risk can be reduced (Velthof and Hummelink, 2011). No measurements of NH3 were available to quantify this risk, but it is clear that the application technique for the NK concentrate is very important in reducing this risk.

Particulate matter: Changes can occur, but not measured.

Nitrous oxide (air), Methane (air): No direct effects on other emissions are expected.

Nitrates (water): Nitrate leaching is being measured, but no results yet, probably if yields remain the same, there will not be an increase in nitrate leaching.

3. Resilience to climate change

Carbon footprint: No changes are expected.

Non-renewable energy consumption: For the manure processing also energy is required (mainly electricity), however, the manure processing is combined with a digester, which provides more energy than required for the process. For energy consumption, negative score is given as consumption will increase for the manure processing. The plant produces biogas, but almost 80% of produced biogas is exported to another: therefore, not used at the plant site. Only 20% of biogas is converted into electricity and used on the site.

Soil quality: Changes are expected, but not measured.

Renewable energy production: As a result of the combination of manure processing with anaerobic digestion, biogas is produced, which delivers renewable energy. In addition, nutrients are recovered, which can replace mineral fertilizers and prevent the fossil fuel emissions related to the production of these fertilizers.

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RL7.LL43 Pig manure evaporation plant (ZLTO)

BRIEF DESCRIPTION OF THE TECHNOLOGY: Pig manure, AD and electricity production, separation digestate, thick fraction in belt dryer, liquid fraction separated in N fraction and K2O fraction using scrubbing and evaporation process.

REFERENCE AGAINST WILL BE EVALUATED: Production and use of mineral fertilizer using Haber Bosch process and mined phosphate.

1. Use of primary resources

Biobased fertilizers are produced from renewable sources: pig manure and coproducts (usually by-products from the food industry).

Rock phosphate: P in thick fraction of digestate will be exported and thus replace rock phosphate in P deficit area's. The solid fraction of the co-digestate is pasteurized and exported to neighbouring countries with a deficit for phosphate and organic matter. This reduces the use of mined rock phosphate.

Natural gas: Saving on use of 'earth-gas' for production of mineral fertilizer. The liquid fraction is processed to a more concentrated nitrogen fertilizer. This biobased nitrogen fertilizer can replace chemical nitrogen fertilizer. Natural gas is still a large and the most preferred source for the production of chemical nitrogen fertilizers because of its high hydrogen to carbon ratio (Parikh et al., 2009). A reduction in the production of chemical nitrogen fertiliser can therefore reduce the use of natural gas.

Oil, Water: No changes are expected.

2. Emisions to the environment

Ammonia (air): The products that are produced during pig manure processing can pollute the environment (Macias-Corral et al., 2008). However, when ammonia scrubbers are used in the process, ammonia emissions are low. According to Melse and Ogink (2005), a reduction in ammonia emission of 40 to 100% can be realised using an ammonia scrubber.

Nitrous oxide (air), Particulate matter: Changes are expected, but not measured.

Methane: The anaerobic digestion unit can reduce methane emissions.

Nitrates (water) and Phosphorus (water): Changes are expected, but not measured.

3. Resilience to climate change

Carbon footprint: This innovation recycles ‘waste’ products and processes these into valuable products that are similar to products that are nowadays still extracted from non-renewable deposits (Chojnacka et al., 2020). The carbon footprint of the produced biobased fertilizers are lower than conventional chemical fertilizer production.

Non-renewable energy consumption: The pig manure is first co-digested in an AD installation. This produces green electricity. Compared to mono-digestion, co-digestion produces more bio-energy (Thyø & Wenzel, 2007; De Vries et al., 2012).

Soil quality: Changes are expected, but not measured.

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

Renewable energy production: Renewable energy is being produced in the anaerobic digester which reduces the need for non-sustainable energy sources.

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RL8.LL22 BIO-PHOSPHATE: high temperature reductive thermal process recovery of concentrated Phosphorus from food grade animal bones (TH)

BRIEF DESCRIPTION OF THE TECHNOLOGY: The purpose/aim of the Bio-Phosphate system is to substitute and replace the high Cadmium and Uranium content non-renewable and imported rock phosphates (different types) based mineral fertilizers with a natural, fully safe, renewable and high efficient organic innovative fertilizer in economical high nutrient concentration for less cost, while mitigating environmental contamination and GHG emissions. The high added value recovered and safe Phosphorus innovative Bio-Phosphate organic fertilizer is produced food grade animal bone grist, which is an unexploited biomass.

REFERENCE AGAINST WILL BE EVALUATED: P fertilizers produced from rock phosphate.

In a world with finite resources there is no infinite development opportunity with sustainability unless full recycling and circular economy is implemented. The agricultural and food product market trend and demand is for the natural and bio based food products with unconditional food safety, but for less cost. This market trend is significantly supported by web information networks that are supporting the awareness of the Consumers towards massive transition into bio-based economy.

However, economic recovery of Phosphorus in economic high nutrient density and purity is challenging. The byproduct streams from the industrialized systems containing dispersed and low P density; while containing wide range of high risk pharmaceutical residuals, illicit drugs and pathogenic contaminations, in some cases overdose of PTE potential toxic elements as well, such as Cu and Zn.

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Upon the use of low nutrient density recovered fertilizers the dose per hectare need to be increased, which is associated with higher dosage speeding of contaminations into soil and sub-surface drinking water reservoirs.

The innovative fertilizer BioPhosphate ABC Animal Bone Char (cattle bone) is a unique case as

a) this is practically free of any contaminations,

b) fully natural and bio product,

c) economically high nutrient density concentrated calcium-phosphate (35% P2O5),

d) having unique and macro porous character,

e) efficiently formulated,

f) the food grade cattle animal bones are available in European dimension and

g) the economical scale industrial technology (3R) is already available.

1. Use of primary resources

Rock phosphate and Nutrients recovered: Large industrial scale recovery of BioPhosphate from the renewable and unexploited biomass food grade animal bones (most importantly cattle bones), which are continuously available in an interesting economical scale.

Natural gas: The BioPhosphate is a natural product , does not contain any chemicals or contaminants.

Oil: Ois is evaluated by the use of agricultural machinery, therefore, not impacted by the technology.

Water: 1 m^3/h of water is used in the plant, but water is recycled in the process.

2. Emissions to the environment

Ammonia (air): Unknown.

Nitrous oxide (air): Unknown.

Methane (air): Unknown.

Nitrates (water): Unknown.

Phosphorus (water): The BioPhosphate product is a controlled release biofertiliser.

Particulate matter: Unknown.

3. Resilience to climate change

Carbon footprint: The production of surplus renewable energy and substitution of mineral fertilizers will reduce carbon footprint. The resilience to climate change of the BioPhosphate ABC Animal Bone Char products are designed to absorb climate shock/stress as well as to self-renew the food crop cultivations towards more sustainability. Climate change is already happening with significant impacts. The BioPhosphate anticipates the risks from climate change and helps coping with the risks via:

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a) improving crop drought tolerance,

b) fully eliminating the release of GHGs during processing,

c) significantly decreasing the release of GHGs during product applications,

d) efficient and rapid restoration of soil natural balance and ecosystem, incl. biodiversity as part of an overall adaptation strategy to adapt to the adverse effects of climate change,

e) creating mechanisms of preventive adaptation for climate change and

f) decreasing ecological and economical vulnerability.

Non-renewable energy consumption: The BioPhosphate is economically produced under zero emission and autothermal processing conditions and carbon negative, while all material streams, including recycled water, are fully recycled and reused. The BioPhosphate global product is renewable and having high nutrient use efficiency.

Soil quality: The economical P2O5 nutrient density of the BioPhosphate is as high as 35%; having high user efficiency and comprehensive safety at less cost under any market competitive conditions, especially in the targeted markets EU, UK, USA, Australia and Japan.

Renewable energy production: The BioPhosphate ABC Animal Bone Char industrial processing in the full industrial scale of 20,800 t/y throughput per installation is zero emission performance. This means that all and any throughput products streams are upcycled into creative and safe natural bio-products and bio-energy for reuse.

Industrial considerations for the emissions to the environment:

1. Input material logistics: high P concentrated input material transported with full optimized transport schedule.

2. 3R processing: zero emission

3. Output material logistics: high P concentrated output material transported with full optimized transport schedule. Formulation is managed regionally, so that part does not require long transport distances.

The applied industrial technology engineering design and industrial implementations in three continents is in harmonized conformity with modern environmental norms and standards of the EU, USA and Australia.

Research line 5. Novel animal feeds produced from agro-residues

The presented research line is defined as new alternatives for animal feedstock. This is a necessity since the import of for instance soybeans used in animal feed is not sustainable. Therefore, six solutions concerning a more circular approach in the scope of animal feed are being described in work package 2. These solutions are described in order to have an idea of their impact on closing nutrient loops and thus their potential to create a more circular agriculture. This report describes some of the environmental performance indicators, subdivided into four parameters:

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- Use of primary resources
- Emissions to the environment
- Resilience to climate change
- Productivity

RL9.LL40 Insect breeding as an alternative protein source on solid agro-residues (manure and plant wastes)

BRIEF DESCRIPTION OF THE TECHNOLOGY: Insects, specifically the Black Soldier Fly (BSF), represent a natural 'food waste conversion engine', and can cheaply and efficiently transform organic waste into complex proteins and fats in their bodies. As the insect larvae eat the food waste, they efficiently synthesise and concentrate the low-value biomass into much more chemically complex and valuable compounds such as proteins and fat – an ideal feed source for farmed salmon and poultry.

REFERENCE AGAINST WILL BE EVALUATED: Manure management without processing

1. Use of primary resources

Nutrients recovered: Processing livestock manure with insects will recover nutrients such as nitrogen, phosphate, potassium and several other minerals. The recovery efficiency will never be 100% and will vary with the substrate. Parodi et al. (2020) reported recoveries of 38 % nitrogen, 28% phosphorous and 14 % potassium on a commercial (non-manure) feed.

Soil quality: The frass (a combination of insect-manure, undigested feed and moltings) still contains organic matter and nutrients that, when applied on the field, will be beneficial for soil quality and will reduce rock phosphate usage.

Natural gas, Oil, Non-renewable energy consumption, Water: However, on the one hand, an insect facility will also consume primary resources such as natural gas (to create artificial climates in which insects thrive), oil (for the transportation of manure to and frass from the insect facility), electricity (to power equipment) and water (for cleaning) (Smetana et al., 2019). On the other hand, this consumption of primary resources is also reduced because of recovered nutrients and less need for mineral fertilizers.

2. Emissions to the environment

There will be less emissions coming from the organic waste. However, emissions related to insect production are possible and are twofold: (i) insects that are processing manure will produce emissions and (ii) emissions might be released when the insect frass is applied on the field. When the insect frass is applied on the field, nutrients that are still present in the frass might cause emissions there as well, these emissions have not been quantified yet.

Nitrous oxide (air) and Methane (air): Primary air emissions such as dinitrogen monoxide and methane have been quantified in BSF in several studies (Ermolaev et al. 2019; Mertenat et al, 2019; Pang et al. 2020; Parodi et al., 2020).

Ammonia (air): Ammonia emissions have been detected as well, but the rate is hypothesized to be strongly correlated with the pH of the substrate. A high pH (like in manure) is linked to detectable ammonia emissions.

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Nitrates (water) and Phosphorus (water): Nitrate and phosphorous may be present in the drain water of an insect facility after cleaning. Moreover, it should be noted that several existing BSF facilities struggle with complaining neighbours due to the typical scent that comes with BSF rearing.

Particulate matter: Emissions not measured yet.

3. Resilience to climate change

Carbon footprint: Several LCA's have been performed on the sustainability of black soldier fly rearing (Smetana et al. 2016; Smetana et al. 2019). Sustainability depends on the feed of the larvae and the application of the larvae. High quality feed for larvae that are used as a feed for chickens is unsustainable. Larvae produced on a waste, that are used in human food are sustainable. Therefore, insects that can be fed on food waste, and with a resulting tiny carbon footprint, represent a massive opportunity for an animal feed industry that is desperate for new sources of high-quality, sustainable feed alternatives.

Soil quality: The frass (a combination of insect-manure, undigested feed and moltings) still contains organic matter and nutrients that, when applied on the field, will be beneficial for soil quality and will reduce rock phosphate usage.

Renewable energy production: Moreover, BSF fat can be converted to biodiesel.

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RL10.LL25 Soybeans in Poland - innovative solutions in the cultivation, plant protection and feeding on farms

BRIEF DESCRIPTION OF THE TECHNOLOGY: The goal of this solution is to increase the effectiveness of domestic cultivation of soybean in Poland by implementing the innovative solutions in soybeans cultivation, fertilization and soya varieties. In addition, the nutrition efficiency of livestock through proper techniques for soybeans treatment such as feeding extruded soybeans to farm animals is expected. This solution is based on the work performed by the operational group "Moja Soja Consortium".

REFERENCE AGAINST WILL BE EVALUATED: Conventional cultivation of soybean in Poland. Non extruded soybeans as feed for farm animals.

1. Use of primary resources

Rock phosphate: Not impacted by the technology.

Natural gas: In soybeans cultivation, the root bacteria inoculated to soil can bind from the atmosphere up to 100 kg N per ha. Due to this, the cultivation of soybeans does not require significant starting doses of N. For example, the starting dose could be about 30 kg per ha (Wenda-Piesik A., 2019b). This in turn could contribute to reduction in resources, e.g. oil or natural gas used for production of fertilizers. However, in this solution the fertilization in the form of potassium nitrate was applied (P_2O_5 - 80 kg/ha, K_2O- 70 kg/ha, N- 40 kg/ha).

Oil: Reduction in logistics of soybean transport from America to Europe reduce oil, but oil will be used in machinery for soybeans in Poland.

Water: Reduction of water consumption due to crop varieties adaptation to different agrosystems and agricultural practices.

Nutrients recovered: Recovery of nutrients from soybean processing waste could be achieved through converting this type of waste through composting with other waste and residues into added value products such as growing media and soil improvers. One of the potential options which is of great interest in terms of vegan agriculture is obtaining plant-based composts and/or soil improvers for vegan agriculture (Schmutz & Foresi, 2017). Due to high N content (about 5.8%) soybeans processing waste could be considered as a substrate or a co-substrate with other plant residues to produce vegan composts. In addition, soybean residues and soybean processing waste could also constitute a source of renewable biomass that can be used as a substrate in a biogas production facilities.

2. Emissions to the environment

Nitrates (water) and Phosphorus (water): Better nutrient crop assimilation, fertiliser reduction due to the use of legumes, reduction of pesticide use.

Ammonia (air), Dinitrogen monoxide (air): better nutrient crop assimilation, fertiliser reduction due to the use of legumes, reduction of pesticide use.

Methane (air): Not impacted by the technology.

Particulate matter: Not evaluated.

3. Resilience to climate change

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

Carbon footprint: In terms of carbon footprint no data was available for this particular solution. However, according to the literature the assessment of GHG emission depends on the land use change in soybean cultivation. For example, Castanheira & Freire (2013) observed significant differences for alternative solutions i.e. 0.1 – 17.8 kg CO_2 eq. kg^{-1} soybean whereas when the land use change is not considered GHG intensity can vary from 0.3 to 0.6 kg CO_2 eq. kg^{-1} soybean.

Non-renewable energy consumption: Treatment of soybeans through extrusion is considered highly energy consuming. It is estimated that the extrusion of 1 ton of soybeans requires 160 kWh (Wenda-Piesik & Doroszewski, 2018/2019).

Soil quality: Cultivation of soybeans is reported to increase soil quality. However, this could depend on the type of soil management, i.e. organic vs. conventional. Marinković et al., 2020 reported that organic soil management improved soil quality by improving soil structure and microorganisms activity (e.g. the abundance of Azotobacter spp., free N-fixing bacteria and actinomycetes) (Marinković et al., 2020).

Renewable energy production: Soybean residues and processing waste as feedstock could be used in anaerobic digestion in biogas plants, specifically in agricultural biogas plants located in the vicinity of soybean farms and/or processing facilities. It is estimated that the average biogas yield (for Favorit variety cultivated in Serbia), for tested five years, was 368 m^3 ha^{-1} (Milanović et al, 2020).) . Also, in solid state digestate soybeans processing waste could be mixed with different co-substrates such as hay (Zhu et al., 2014). Other than that waste soybean oil could be also used for production of biodiesel.

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RL10.LL45 INPULSE: Innovating towards the use of Spanish legumes in animal feed

BRIEF DESCRIPTION OF THE TECHNOLOGY: The advantages of growing legumes for animal feed and replacing soybean are studied in this solution. Soybean is almost entirely imported from America. Crops will be selected on the basis of geoclimatic factors to increase crop yield, nutrient efficiency, water consumption, etc.

REFERENCE AGAINST WILL BE EVALUATED: In the current scenario, soybean used for animal feed is imported from America.

1. Use of primary resources

Grain legume cultivation is continuously decreasing in Spain in spite of the long tradition of their cultivation and consumption and their well-known environmental benefits by improving soil fertility. Grain legumes have been replaced in rotations by other crops that have adapted more quickly to technological progress and are more profitable for farmers in the short term. A similar change is taking place in Europe. This generates two major dependencies that can only be alleviated by increasing legume cultivation. In Spain, we import 4.7 million tons of grain legumes yearly, most of which is soybean (95% of the total). This dependency on imports, particularly on soybean, poses a serious threat to the economy as it makes the raw feed industry, and therefore most of the meat industry, vulnerable to fluctuations in the world soybean price (Gonzalez-Bernal & Rubiales, 2016). The most cultivated legume in Spain is the dry pea, with an area of 164,300 ha (average 2011-16, according to MAPA (2020) figures), which accounts for almost 75% of the cultivated area of grain legumes in Spain. In fact, the pea is the only grain legume whose cultivation has increased in Spain since the 90's of last century, having reached over 240,000 hectares in 2011. Soya is the most consumed legume and at the same time the least cultivated and produced in Spain (only 670 hectares and 1,800 tonnes on average 2010-15, MAPA). The decline has also occurred in other crops such as beans or dried beans (with a marked fall until 2013 and slight recoveries to 45,700 ha and 9,300 ha in 2016 respectively), or yeros (which have stood at 71,700 ha compared to 79,100 ha on average 2011-16, according to MAPA figures).

Rock phosphate: Not known yet compared to the baseline.

Natural gas: Not known yet compared to the baseline.

Oil: Not known yet compared to the baseline.

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Water: Reduction of water consumption due to crop varieties adaptation to different agrosystems and agricultural practices. Promoting the rational cultivation of legumes will lead to a reduction in water consumption and soil protection due to the adaptation of crop varieties to different agricultural systems and practices.

Nutrients recovered: Better nutrient crop assimilation, fertiliser reduction due to the use of legumes, reduction of pesticide use. The cultivation of legumes will lead to a better assimilation of nutrients from the crops, a reduction in fertilizers and a reduction in the use of pesticides

2. Emissions to the environment

Ammonia (air): Better nutrient crop assimilation, fertiliser reduction due to the use of legumes, reduction of pesticide use.

Nitrous oxide: Legumes are key multifunctional crops for agriculture, the environment, food and culture. They are capable of fixing atmospheric nitrogen, are key in rotations, improving soil structure, capable of breaking cycles of diseases and pests, improving biodiversity, N2O emission, CO2 capture, and of great interest for animal feed, as feed and fodder. According to Ma et al. (2018) 25% of the yield-scaled N2O-N emission would be saved by switching to a legume rotation under climate change conditions.

Methane (air): Not impacted by the technology.

Nitrate (water) and Phosphorus (water): Better nutrient crop assimilation, fertiliser reduction due to the use of legumes, reduction of pesticide use.

Particulate matter: Not evaluated by the technology.

3. Resilience to climate change

Carbon footprint: Furthermore, from an environmental point of view, international trade in feed materials has high impacts. For example, with regard to the carbon footprint or the large flows of nitrogen in the form of proteins, due to inefficiency in the use of this and the inability to close the nutrient cycle (Billen et al. 2015; Leip et al., 2015). In this sense, Lassaletta et al. (2016) conclude that it would be possible to optimize global food levels by improving regional self-sufficiency, in addition to generating less nitrogen pollution than at present.

Non-renewable energy consumption: Not known yet compared to the baseline.

Soil quality: Soil protection due to crop varieties adaptation to different agrosystems and agricultural practices and reduction of fertiliser and pesticide use. Legumes have clear environmental benefits in terms of improving biodiversity and soil quality, as well as providing pollination and nesting areas for insects and bees, as well as for birds.

Renewable energy production: Not impacted by the technology.

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RL11.LL34 Secondary harvest: additional valorisation of crop harvest and processing residues

BRIEF DESCRIPTION OF THE TECHNOLOGY: When harvesting grass, it is important to apply “selective mowing” as much as possible : areas that are of high quality can be used as animal fodder; other areas result in grass clippings of lower quality and cannot be used as fodder but can be valorised through alternative processing (proteins or insolation materials). An experienced farmer will know how to make the selection on sight while mowing (for example the very toxic Senecio Jacobea cannot be harvested). The grass clippings coming from part of this area is of higher quality because of selective mowing and can therefore be harvested as animal feed, or for other purposes.

REFERENCE AGAINST WILL BE EVALUATED: Grass is harvested, collected and composted "in situ"

1. Use of primary resources

Water, Oil and Natural gas: Based on nutritional values, the production of hay is 4 times more efficient than natural grass for animal feed. Thus, the use of 4 ha grass clippings from natural reserves can replace 1 ha of cultivated hay land. This results in reductions in nutrient gift, in water gift, in land labour and in land use.

Rock phosphate, Nutrients recovered: At the same time, when natural grass is used for animal feed instead of composting in situ, the potential for organic C recycling is 2.65 ton/year/ha, for N recycling 1.05 ton/year and for phosphate recycling is 0.017 ton/year.

2. Emissions to the environment

Nitrates (water), Phosphorus (water), Methane (air): When natural grass is harvested for animal feed instead of locally composted in situ, farmers need 25% less hay production which results in a saving of emissions. Furthermore, emissions of the composting process are avoided.

Ammonia (air), Nitrous oxide (air) and Particulate matter: Indicators not measured, but may have impact.

3. Resilience to climate change

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

Carbon footprint: When the grass clippings are removed from natural reserves, the nutrients are exported. Reducing nutrients on these soils will increase biodiversity.

Soil quality: When it comes to the use of primary resources, the selective harvest of natural grass can result in 2.6 tonnes organic carbon/ha for animal feed. In this example 920 tonnes organic carbon is produced a year on 350 ha natural reserve, which replaces 175 ha of hay. The nutritional values of natural grass are only 50-60 % of hay.

Non-renewable energy consumption: No impacts are expected for this indicator.

Renewable energy production: This solution does not have any influence on renewable energy production and increasing effective SOM.

References

The data for natural grass are obtained by analysing grass from the natural reserve “de Zwarte Beek”, which were compared with databases of other animal fodder.

RL12.LL41 Floating wetland plants grown on liquid agro-residues as a new source of proteins

BRIEF DESCRIPTION OF THE TECHNOLOGY: This solution presents the production of duckweed (species Lemna minor) on biological effluent from the treatment of pig manure. Consequently, the biomass is fed to pigs. This is done in an outdoor pond of which the bottom is covered with a plastic foil. The duckweed is supplied directly without a processing step to pigs as a protein source. The high productivity of 3 ton protein per hectare per year makes it three times more productive in terms of cultivation area than conventional land bound protein crops.

REFERENCE AGAINST WILL BE EVALUATED:

1) Tertiary treatment of constructed wetlands using reed

2) Huge imports of protein rich soy from North and South America

1. Use of primary resources

Rock phosphate, Nutrients recovered: Biological effluent has a remaining P and N concentration that can be taken up partly by duckweed and is reused in the feed chain. The N and P excess in Flanders amounts around 9000 tonnes N and 10.000 tonnes P in Flanders (VLM, 2018). Secondly, a primary source for animal husbandry in Europe is soybean meal. In 2019 the net use of soybean meal was 29.6 million tonnes, of which only 3% was produced in Europe (European Commission, 2020).

Natural gas: No changes are expected.

Oil: Fuel costs are greatly reduced in a local system, because transport for the treatment of manure is reduced, and tranport of feed is reduced. But fuel costs increase when external heating, and extra light is provided. Also, when duckweed is dried, energy costs increase largely.

Water: Water is necessary for the crop production because of evaporation, yet, intellegent design can reduce the need for water to a minimum, yet, more information is necessary.

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2. Emissions to the environment

Emissions of duckweed ponds are largely under-investigated. One study emissions in a duckweed pond containing stormwater, resulting in CH_4 emission rates ranging from 502 to 1900 mg CH_4 m^{-2} d^{-1} while those of nitrous oxide (N_2O) ranged from 0.63 to 4 mg N_2O m^{-2} d^{-1}. The CO_2 emission rates ranged from 1700 to 3300 mg CO_2 m^{-2} day^{-1}. In total, this is an emission of 14 to 52 g CO_2-eq m^{-2} d^{-1} (Sims et al., 2013). However, during growth, CO_2 is captured by photosynthesis. In a recent study of Mohedano et al. (2019), it was shown that duckweed ponds have a net carbon capture of at least three times more CO_2 than it emits, at low carbon loading ranges.

Ammonia (air): Ammonia volatilsation is possible, but at neutral pH this does not occur (Körner, 2003). (<1.5% zimmo et al. 2003) Importance of pH.

Methane (air): No changes are expected.

Nitrous oxide (air): It should be mentioned that N_2O was not determined.

Nitrates (water) and Phosphorus (water): Using a plastic foil to cover the bottom of the pond prevents any leaching of nutrients.

Particulate matter: No measured.

3. Resilience to climate change

Carbon footprint: Furthermore, the current soy import has an additional environmental impact due to land use change (Reckmann et al., 2016). In a study by Meul et al. (2012), it was calculated that a reduction of 15 g CO_2-eq/kg compound feed (=2.5%) is possible when replacing imported soy by local soy in the Dutch situation in 2012. Furthermore, a reduction of need for synthetic fertilisers for feed production reduces the environmental impact. Finally, the reduced import of soybean and larger local dependency has also a reduction effect on the carbon footprint of feed production.

Non-renewable energy consumption: Compared to most land crops, electricity is more needed for harvest, and perhaps processing. Yet, compared to algae, constant rotation and harvest requires less energy.

Soil quality and Renewable energy production: No changes are expected.

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RL24 Algae grown on nutrient rich liquid agro-effluents as a new source of proteins

BRIEF DESCRIPTION OF THE TECHNOLOGY: Protein rich microalgae are already commercialized as high value food and feed ingredient due to its composition rich in antioxidants, vitamins and other growing factors besides their high protein content. One of the main expenses associated with this production is the cost of nutrients. The association of microalgae cultivation and digestate could lower these costs, making this product more economic attractive while recovering nutrients, especially N, from this stream and reducing the risk of eutrophication associated with the direct application of high volumes of digestate to the soil.

REFERENCE AGAINST WILL BE EVALUATED: Liquid fraction of digestate applied to the field

1. Use of primary resources

Rock phosphate: During microalgae growth on liquid agro-residues, such as digestate, the main nutrients are directly supplied without the need for additional primary resources. However, the additional supply of phosphate might be needed, as few digestate sources may be poor in soluble P (Marcilhac et al., 2015).

Oil: No impacts are expected in this indicator.

Water: The tap water is used for digestate dilution and for algal growth but might be recirculated after membrane filtration, thereby reducing overall water demand (Fret et al., 2020).

Soil quality, Natural gas and Nutrients recovered: The algae cultivation on digestate also helps in avoiding over-application of excess N from digestate to the field (Chuka-ogwude et al., 2020; Xia & Murphy, 2016). In terms of resource recovery, the renewable algal biomass recovers N and minerals from digestate for protein production with efficiencies close to 100%, depending on the cultivation conditions (Koutra et al., 2018).

2. Emissions to the environment

Ammonia (air) and Nitrous oxide (air): The nitrogen-based emissions are limited during algae growth on digestate in closed bioreactors. Reduced levels of ammonia and dinitrogen monoxide emissions are possible during bioreactor operation due to high pH buffering capacity of digestate and ammonia-oxidation bioprocess, respectively (Mezzari et al., 2013).

Nitrates (water): High levels of ammonia release and nitrate discharge into water bodies are avoided by diverting land application of digestate towards algae cultivation. This is because ammonia within digestate is converted to nitrate when applied to the soil, which is prone to surface run-off and causes nitrate-polluted water bodies.

Phosphorus (water) and Particulate matter: In terms of phosphorus and particulate matter emissions, soluble phosphate available in digestate is used up by the algae cultures which, upon dewatering, produces clear and dischargeable liquids free of soluble phosphate and particulate matter (Torres Franco et al., 2018).

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Methane (air): No impacts are expected in this indicator.

3. Resilience to climate change

Carbon footprint: Higher levels of carbon dioxide emissions can be put off as algae consumes CO2 as inorganic carbon source and for pH control (D'Imporzano et al., 2018). Algae offer promising CO2 sequestration capacity by utilizing it as inorganic carbon source and for pH control. If industrial CO2 or waste recovered CO2 can be provided, algae actively assist in large-scale CO2 mitigation to produce protein-rich biomass. This biomass could present a future alternative to replace imported protein in Europe, further mitigating climate change emissions associated to transcontinental transportation (Vigani et al., 2015).

Non-renewable energy consumption: The electricity requirement is high during digestate pre-treatment, operation of closed bioreactors, and harvesting systems.

Renewable energy production: No impacts are expected in this indicator.

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