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Nutri2Cycle
Nurturing the Circular Economy

Nutri2Cycle

D.3.5 White book for sustainable farms

Deliverable: White book for sustainable farms

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Abbreviations

CAPEX: Capital Expenditure

EU: European Union

FG: Focus Group

MCA: Multi Criteria Analysis

N: Nitrogen

N2C: Nutri2Cycle

N_2O: Nitrous Oxide

NDVI: Normalised Difference Vegetation Index

NVZ: Nitrate Vulnerable Zones

OPEX: Operational Expenditure

PA: Precision Agriculture

RENURE: Recovered Nitrogen from Manure

RDF: Recycling Derived Fertilisers (RDFs)

SOM: Soil Organic Matter

TRL: Technology Readiness Level

UAA: Utilised Agricultural Area

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Glossary

Agro-typology: Agricultural system as a wider term which emphasizes on the functional attributes which be a single farm or a group of inter-related farms having similarities of agricultural attributes

Ammonium stripping/scrubbing: Technology that aims to strip the ammonia from airflows by “washing” it with an acid solution. The result of the stripping is on one hand a filtered air flow (low in emissions) and on the other hand a liquid solution containing ammonium. Depending on the acid used (HNO_3 or H_2SO_4), this liquid solution is ammonium nitrate (AN) or ammonium sulphate (AS).

Anaerobic digestion: A series of biological processes in which microorganisms break down biodegradable material in the absence of oxygen and produce biogas.

CAPEX: Capital expenditure - funds used by a company to acquire, upgrade, and maintain physical assets such as property, plants, buildings, technology, or equipment.

Cost benefit analysis: A cost-benefit analysis is the process of comparing the projected or estimated costs and benefits (or opportunities) associated with a project decision to determine whether it makes sense from a business perspective.

Digestate: A nutrient-rich substance produced by anaerobic digestion that can be used as a fertiliser.

Floating wetland plants grown on liquid agro-residues: Recuperation of nutrients from liquid agro-residues by growing protein-rich floating wetland plants.

Gross margin calculation: Net sales less the cost of goods sold (COGS); the amount of money a company retains after incurring the direct costs associated with producing the goods it sells and the services it provides.

High temperature reductive thermal process recovery of concentrated phosphorus from food grade animal bones: Technology that aims to recover phosphorus from food grade animal bone by-products using specialized pyrolysis processing technology and animal bone char product (ABC - BioPhosphate) development.

NDVI Normalised Difference Vegetation Index : graphical indicator from remote sensing measurements, assessing live green vegetation.

Nitrification-denitrification: Nitrification occurs under aerobic conditions and is the first step of biological wastewater treatment. Nitrification is a microbial process during which ammonium is converted to nitrite and then nitrate. Denitrification occurs under anaerobic conditions and is the second step in biological wastewater treatment. The nitrate (and nitrite) from the previous step is now reduced to molecular nitrogen (N_2) and nitric oxide. The objective of the couple process of nitrification-denitrification is the removal of reactive inorganic nitrogen from wastewater in a preferably harmless way.

OPEX: Operating expenses - costs a company incurs for running its day-to-day operations (rent and utilities, wages and salaries, property taxes).

Pig manure evaporation plant: Technology that aims to process all fractions of the pig manure into separate fertilizer products for N, P and K. N is recovered using N-stripping technology and the K-concentrate remains after evaporating water.

Precision farming: A farming management concept based on observing, measuring, and responding to inter and intra-field variability in crops; concept of improving crop yields and assisting management decisions using high technology sensor and analysis tools.

Struvite crystallisation**:** Crystallization of nitrogen and phosphorus in the form of magnesium ammonium phosphate hexahydrate (MAP).

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Executive Summary

This "White book for sustainable farms" provides an overview on the CNP (carbon, nitrogen, and phosphorus) challenges faced by different agrotypologies within the EU production systems and how the solutions proposed within the Nutri2Cycle project are able to cope with them.

The identified agrotypologies include the group of livestock production (pig, cattle and poultry), plant production (cereal and maize, vegetables and orchard), and processing (slurry, byproducts and agroenergy), which links livestock and vegetable production.

Livestock agrotypologies face challenges such as intensive production, reliance on imported feed, nutrient overload, and difficulties in slurry management. Plant production agrotypologies face challenges such as dependence on synthetic fertilisers, lack of organic matter, degradation of soil quality, and the need for more effective nutrient use.

The solutions proposed within the Nutri2Cycle project act on four main strategies: decreasing feed and nutrient imports, increasing nutrient exports, improving nutrient use efficiency, and importing recovered CNP from other areas or sectors. These strategies aim to address the issues related to nutrient overload, feed dependency, and carbon depletion in the soil.

Finally, a multi-criteria analysis (MCA) is used to evaluate the proposed solutions. MCA considers multiple criteria and objectives, integrating factual information, stakeholder perspectives, and contextual constraints to identify suitable courses of action. The criteria used for the MCA include local and global environmental impacts and economic sustainability to focus on stakeholders' perspectives and contextual constraints.

Clusters of economically sustainable and environmentally beneficial solutions and the support measures required for their implementation are identified. In nutrient-rich regions, the solutions can be positioned according to four different economic clusters, and the distinction allows to frame which are the necessary support measures for a large implementation of solutions. In nutrient-poor areas, solutions involving the import of recovered nutrients are economically advantageous and complement the export strategy in nutrient-rich areas. Increasing nutrient efficiency is crucial for all these solutions, in both nutrient-rich and nutrient-poor areas, to effectively close the CNP cycle. Thus the combination of solutions that support the import/export strategy and increase nutrient efficiency is the pathway to effectively reach the CNP cycle closure within the agrotypology in Europe.

Introduction

1. Background in the project and objectives

Nutri2Cycle project has the objective of proposing and investigating solutions able to close the current gaps in the N, P and C cycles of different European agricultural systems, addressing the related environmental problems and finally proposing operative synthesis.

The operative **phases of the Nutri2Cycle project** are:

- map and comprehensively present the current flows and gaps in C, N and P cycles over three central agricultural pillars,
- find, select and prioritise innovation by the innovation funnel
- investigate prioritised solutions
- support further development and testing of innovations in demos
- implement a toolbox of comprehensible indicators to measure sustainability & evaluate trade-offs between the current practice and innovative, optimised farming systems for the investigated typologies
- impact calculation at the regional & EU level
- evaluation on how agro products obtained via more sustainable processes can aim for eco-labelling and how this could affect consumer behaviour (willingness to pay)

The Deliverable 3.5, "White book for sustainable farms", aims to frame the advantages of the investigated solutions concisely and how they can be integrated across the Agrotypologies in the EU.

This report is part of WP3 – Impact assessment: determining the environmental, economic and agronomic impact of innovative solutions for closing C, N, and P loops and benchmarking these against the current baseline; task 3.4.2 White book for sustainable farms has the objective to combine the improving practices, innovations and management changes into a "white book for sustainable farms", classified per studied Agrotypology considering the peculiarity of each Agrotypology.

To this purpose agrotypologies previously identified as fundamental in the N2C concept (as they include and connect in a cycle, all the agricultural sector's significant productive and transformation assets) are analysed in terms of problems and challenges concerning the CNP cycle closures. At the same time, solutions investigated in the N2C project are presented according to their applicability and ability to solve the specific problems and challenges of each agrotypology.

The agrotypologies considered are:

- ANIMAL: pig, poultry, and cattle
- CROP: vegetable cereals & maize, orchard, organic/agroforestry
- AGRO-PROCESSING: framed as the tools able to improve and facilitate the closure of the CNP cycles in the EU agricultural system, linking ANIMAL and CROP agrotypologies. Main

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processing typology being: i) anaerobic digestion/agro-energy, ii) manure processing, iii)agro by-product processing (other than manure)

Finally, a Multi-Criteria Analysis (MCA) presents the synthesis of i) how solutions can be clustered according to different stakeholders' perspectives and specific contexts, ii) the potential applicability iii) the type of support needed to scale up the implementation.

2. Agrotypologies overview

The agro-typologies identified as the foundations of the EU production system are those linked to livestock production (pig, cattle, and poultry), plant production (cereals, vegetables and fruits) and finally, the agro-typologies identified in the N2C concept as processing, i.e., the agro-typologies linking livestock and vegetable production by processing the by-products. Many of the solutions and tools proposed within the N2C project are born within the "processing concept" to improve the management of CNP cycles in agriculture.

As will be seen in detail in the dedicated chapters, the CNP issues related to livestock agrotypologies are mainly i) the intensive production, ii) the reliance on imported feed and, as consequences: iii) nutrient overload and iv) difficulties in the management of slurry.

The challenges faced by the agrotypology of plant production (cereals, orchard agroforestry) are instead different and sometimes complementary: namely i) the dependence on synthetic fertilisers, ii) the lack of organic matter and iii) the degradation of soil quality, iv) the need for more effective use of nutrients and namely or recovered nutrients.

The solutions identified within the N2C project work mainly on four strands of strategies to allow and make the closure of the CNP cycles more environmentally efficient:

- Decrease feed and other NP import **(DI) from non-renewable sources,** thanks to the valorisation of local resources and new circular production pathways, thus decreasing the nutrient pressure in livestock areas and addressing the issues related to feed dependency (food security) and N and P surplus.
- Increase export of nutrients **(EX),** thus supporting the viability of nutrient transport and export from surplus areas to other areas.
- Improve the efficiency of the nutrient use **(NU),** decreasing nutrients wastage in the environment (NH_3 emissions, N leaching and GHG emissions such as N_2O).
- Import of recovered CNP from other areas or sectors **(I),** i.e., the recovery and valorisation of streams, such as slurry or sewage sludge and by-products, in the regions that are poor in nutrients. The strategy addresses the challenges related to NP dependency from non-renewable sources (chemical N and mined P) and carbon depletion in soil (causing degradation and fertility decline).

Indeed, the fourth strategy is specular to the second but applied to nutrient-poor regions and agrotypologies such as vegetables, orchards and cereals when grown far from livestock districts.

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The group of processing agrotypologies is considered as a distinct pillar to outline their relevance at the EU level, as processing is the tool through which the flow of CNP can find the best and most effective closure, as these agrotypologies make possible, through processing, the export **(EX)** and the increase of nutrient efficiency **(NU)**

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3. Pig Agrotypology

Sander Vandendriessche, Provincial Research and Advice Centre for Agriculture and Horticulture (Inagro vzw), Belgium

Sector outline

Pig husbandry is a relevant sector in Europe, with about 142 million pigs (Eurostat 2020). It represents the largest livestock category before that of the bovines, and the EU pig meat sector alone accounts for nearly half of total EU meat production. In 2018, the overall production of pig meat was 23.8 million tonnes. The EU is the world's second larger producer of pork after China and the biggest exporter of pork and pork products (Augere Granier, 2020). In the EU, 50% of pig meat is produced by three big countries (Germany, France, and Spain). Intensive production occurs in Denmark, the Netherlands, Belgium and northern Italy.

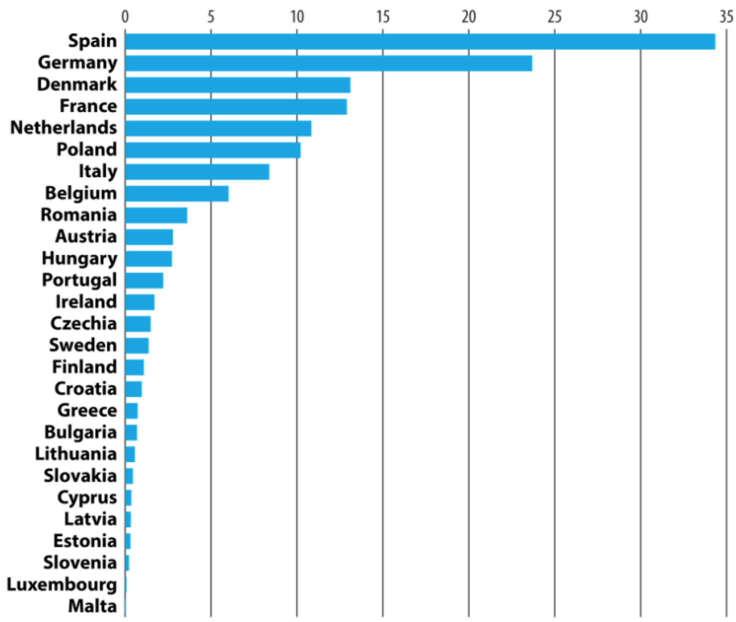

Figure 1:Pig Population in Europe, 2021 (in millions). Eurostat

The sector is highly diverse, with considerable differences in rearing methods and farm sizes across the Member States. Pig farming is mainly concentrated in several specific regions: Capital, Central Jutland and North Jutland in Denmark, North Brabant in the Netherlands, West Flanders in Belgium, as well as western Lower Saxony and the northern parts of North Rhine-Westphalia. Other regions

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with a relatively high density of pigs include Catalonia, Aragon and Murcia (Spain), Brittany (France), Lombardy (Italy) and Wielkopolskie in central Poland. To some degree, the location of pig farming in Europe is linked to easy access to animal feed, and some regions mentioned above are close to seaports where imported feed is landed.

In Figure 2 the share of UAA dedicated to the pig agrotypology at NUTS 2 level in the EU and the share of LSU dedicated to the pig agrotypology is reported, to frame the situation of the agrotypology. Figure 3 reports the areas with manure surplus and the areas with N soil surplus in the EU, to frame the situation in respect to CNP closure. The elaboration is made on arable land, although the maps in Fig.3 are not for pigs specific, a clear relation between pig coverage and N and P surplus exists. Note that the model used to create the maps of Fig.3 (MITERRA-EUROPE) includes only managed grassland, but no (semi)natural grasslands, which can be a major grazing type in some regions in Europe, i.e., Cyprus. In these regions, this can lead to an overestimation of the soil N and P surplus.

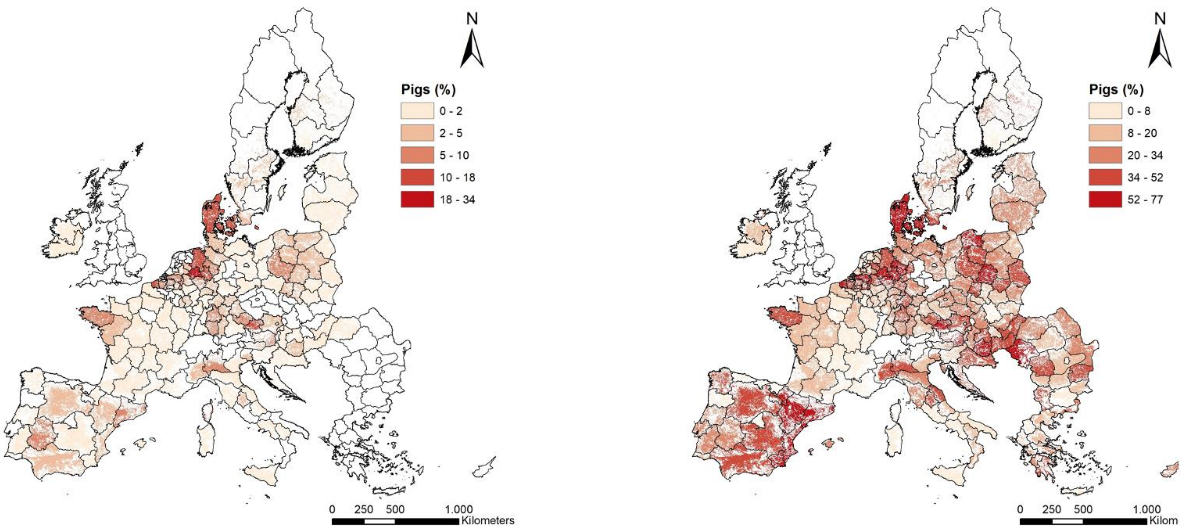

Figure 2: Share of UAA dedicated to pig agrotypology at NUTS 2 level and share of LSU dedicated to pig agrotypology. The maps are based on data of the Farm structure survey of Eurostat.

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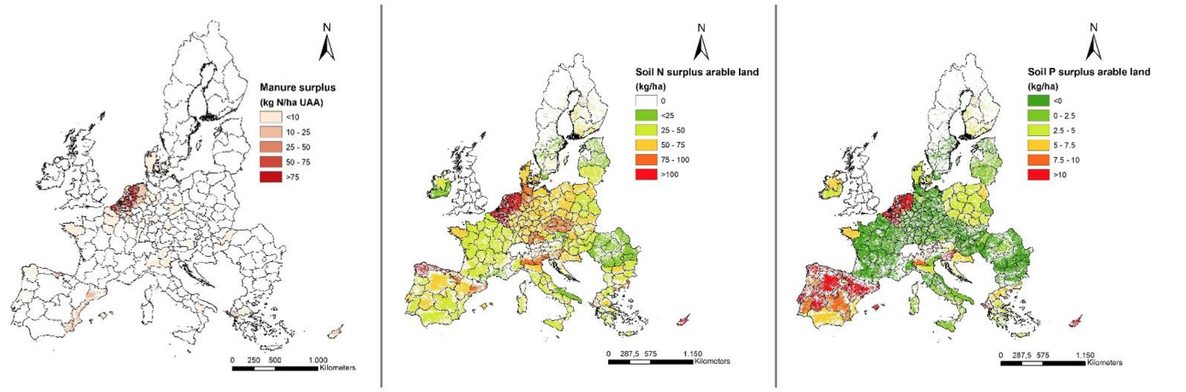

Figure 3. Areas with Manure surplus and soil N and P surplus at NUTS 2 level. The maps are based on results of the MITERRA-Europe model (https://edepot.wur.nl/547940)

Table 1. Pig Agrotypology factsheet

Parameter	Unit	Value	Source
Herd number in EU	n	142 million	Eurostat
Turnover	€	85 billion	Peyraud 2020
Number of companies in EU	n	136,500	Eurostat
Agricultural area dedicated in EU	ha	8.5 million (the land required to grow feed for EU pork)	Ermgassen 2016

Problems and challenges related to CNP closure.

Intensive pig husbandry has several key challenging consequences, the main of which, related to CNP cycles, are reported in Table 1.2, with a qualitative estimation of the extent.

Table 2:Extent of the problems related to CNP cycles in pig agrotypology

Problem	Extent of the problem
N surplus	+++
P surplus	++
NH_3 emissions	+++
N leaching	++
GHG	++
NP dependency from non-renewable source	-
Feed dependency and food security	+++
Carbon depletion/soil degradation/fertility decline	-

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- no problem
+ minor problem
++ problem
+++big problem

N surplus and feed import: In detail, pig manure strongly contributes to the nutrient surplus in certain regions in Europe (where intensive pig husbandry is located), and the import of feed from oversea causes a further imbalance of nutrients. According to FAO statistics, the EU-27 yearly imports around 20 million tons (Mt) of soybean meal (net import) and 12 Mt of soybean, of which some 10 Mt is processed into meal, taking the total EU-27 consumption of soybean meal to some 30 Mt, of which a significant part is necessary for the pig sector. The EU-27 soybean crop production stands at 1 Mt (around 0.8 Mt soybean meal). So only 2.5 % of the EU-27 soybean meal consumption is produced in the EU-27 (Slinkard 2019).

Ammonia emissions: Manure quality and composition, handling and disposal, determine the extent to which harmful elements are emitted at the farm level. The primary effects of intensive pig farming and slurry mismanagement include **air pollution**, particularly ammonia and nitrous oxide (N_2O), and **surface water and groundwater pollution** by nitrates and ammonium. Therefore, the field application of pig slurry (and manure generally) is limited to 170 kg N/ha due to the Nitrates Directive leading to **high manure processing costs**.

Emissions of greenhouse gases (GHG): the large amount of N in slurry, oversupply exceeding the N needs, and specific pedoclimatic conditions determine increased nitrous oxide (N2O) emissions. Again, applying slurry to soil may also cause methane emissions (CH_4).

Other environmental issues include local disturbances, such as odour and noise, the spreading of heavy metals, pesticides, toxic substances and pathogens (including antibiotic-resistant pathogens), water pollution by residues of pharmaceuticals, excessive use of groundwater, etc.

The N crisis is a hot topic in intensive pig husbandry regions due to the aforementioned consequences. This leads to discussions of measures to reduce livestock. Despite these actions, viable solutions like those presented in the Nutri2Cycle project have emerged, offering ways to address and mitigate nutrient-related issues in these regions. Such solutions are crucial in safeguarding the economic sector and preserving job opportunities.

Furthermore, pig farmers face several other challenges, such as high production costs and low meat prices. Even the most efficient herds are losing more than 40 EUR per pig [8]. Two possible reasons for this are the increasing attention to environmental issues and animal welfare.

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Next to costs, climate change may indirectly reduce EU pig productivity by reducing the availability of crops usually used in pig feeding and directly by inducing heat stress and increasing the animal's susceptibility to various diseases (Renaudeau 2022).

N2C solutions tackling the CNP challenges

Within N2C, thirteen solutions can work on various CNP nutrient management challenges observed within the pig Agrotypology system. The solutions tackle the main challenges of the sector according to the following strategies:

- Decrease feed import (DI), mainly decreasing N and P surplus, decreasing feed dependency and increasing food security.
- Increase export of nutrients (EX), mainly.
- Improve the efficiency of the nutrient use (NU), thus reducing NH_3 emissions, N leaching and GHG emissions (such as N_2O).

Table 3. Solutions applicable to pig agrotypology and strategies to tackle the CNP challenges.

LL number	Title of the solution	Strategy		
		DI	EX	NU
25	Soybeans in Poland - innovative solutions in the cultivation, plant protection and feeding on farms	X		
45	INPULSE: Innovating towards the use of Spanish legumes in animal feed	X		
40	Insect breeding as an alternative protein source on solid agro-residues (manure and plant wastes)	X		
41	Floating wetland plants grown on liquid agro-residues as a new source of proteins	X		
41B	Algae grown on nutrient rich liquid agro-effluents as a new source of proteins	X		
24	Adapted stable construction for separated collection of solid manure and urine in pig housing (followed by separate post-processing)		X	X
18	Slurry acidification with industrial acids to reduce NH_3 volatilization from animal husbandry			X
19	Slurry bio acidification using organic waste products to reduce NH_3 volatilization and increase fertilizer value			X
49	Nitrogen and phosphorus recovery from pig manure via struvite crystallization and design of struvite based tailor-made fertilizers	X	X	X
20	Low temperature ammonium-stripping using vacuum	X		X

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23	Pig manure refinery into mineral fertilizers using a combination of techniques applicable at industrial pig farms	X	X
43	Pig manure evaporation plant	X	X
10	Small / Farm scale anaerobic digestion to increase local nutrient cycling & improve nutrient use efficiency		X

i) LL25 Soybeans in Poland - This solution looks into the possibilities of effective domestic cultivation of soybeans in Poland. Moreover, it aims to increase the nutrition efficiency of livestock through proper techniques of soybeans treatment. So this solution addresses the CNP problems by decreasing feed import and the related nutrient overload problem.

ii) LL45 INPULSE - The INPULSE Operating Group (GO_INPULSE) was created to strengthen the cultivation of legumes in Spain in order to reduce the external dependence of protein for feed through the design and evaluation of a systematised mechanism of use of legumes, adapted to the needs of the entire chain. Similarly to LL25, this solution is working on reducing feed import.

iii) LL40 Insect breeding – This solution aims to provide an alternative source for proteins by using side streams and by-products from agriculture, which can be used as insect rearing substrates. Insects can be an alternative protein and fat source for feed, and the solid fraction of pig manure can be a good substrate for rearing. So, this solution is also working on the challenge of protein import (e.g., soybean) by looking for alternatives, but at the same time, it could also offer a solution for manure excess.

iv) LL41 Floating wetland plants –This solution looks into the possibilities of cultivating duckweed recuperating nutrients from liquid agro-residues. This small plant can convert the removed nutrients in the wetland to proteins, which can be a feed ingredient for animals due to its high protein content. As a consequence, it can substitute commonly imported protein sources. Since it can be cultivated on the biological effluent of a pig manure treatment facility, this solution can close nutrient loops on the farm level. As for solution LL40, this solution is working on decreasing feed import (e.g., soybean) and managing manure excess.

v) LL41b Algae – Like LL41, algae can be cultivated on liquid agro-residues and provide alternative proteins. In this specific solution, the nutrient-rich liquid fraction of digestate was considered as a promising substrate for microalgae biomass production. Besides protein, microalgae contain diverse nutritive value compounds such as lipids, pigments, minerals, peptides, carbohydrates, antioxidants, and trace elements. Again, the solution contributes to decreasing feed import (e.g., soybean) and managing manure excess.

vi) LL24 Adapted stable construction – This solution ensures a source separation of pig urine and solid manure to reduce emissions (mainly NH_3) in the stables. As an additional advantage, the resulting products each have a higher value: the pig urine (containing most of the N and K) has an improved nutrient use efficiency compared to the pig slurry, while the solid pig manure (containing most of the C and P) is a suitable substrate for farm scale AD and it is easier to export.

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vii) LL18 and LL19 Slurry (bio)acidification – Acidification or lowering the pH of pig slurry can be an effective tool to reduce gaseous ammonia and methane emissions along the slurry management chain. In terms of N, higher mineral fertiliser replacement values can be achieved and reduced N-leaching in the field has been identified, which again results in reduced environmental pressure relative to the field application of non-acidified slurry and increased yields.

viii) Other solutions (LL49, LL20, LL23, LL43 and LL10) can all be (directly) linked to the pig sector but are, in fact, manure processing solutions. A description of these solutions can be found in Chapter 10, Manure processing.

Requirements

The specific requirements for applying each solution at the farm/company level are listed in the tables below.

Table 4. Requirement for implementing solutions in pig agrotypology

Solution LL25: Soybeans in Poland
Requirement 1: Access to a sufficient area to cultivate soybeans (the cultivation may be at the expense of other crops)
Requirement 2: A suitable soybean variety should be selected, able to maximize the yield and minimize the costs to cultivate soybeans in each climate condition effectively
Requirement 3: Farmers need to invest in extruders for the production of soybean forage ready for feeding in their own livestock production

Solution LL45: INPULSE
Requirement 1: Access to an appropriate land area on which to cultivate legume crops (the cultivation may be at the expense of other crops)
Requirement 2: Access to a variety of locally adapted legume breeds that provide more constant production and that allows a constant supply in quantity and quality for the feed processing industries
Requirement 3: Analytical facilities to determine the nutritional value of different grown legume varieties

Solution LL40: Insect breeding
Requirement 1: High investment cost in breeding facilities. It also requires extra operational costs (e.g. energy)
Requirement 3: Access to a continuous and constant agro-residue stream as rearing substrate

Solution LL41: Floating wetland plants
Requirement 1: Access to a sufficient area to install the pond
Requirement 2: An initial investment is necessary
Requirement 4: Skilled technical staff is needed to manage the process

Solution LL41b: Algae
Requirement 1: ~1 ha land for cultivating 10-13 ton of protein algae and treating 450m^3/y of digestate

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Requirement 2: Own anaerobic digestion plant or be located near one for digestate supply
Requirement 3: If located in NW Europe, a greenhouse to maintain optimal temperatures year-round

Solution LL24 Adapted stable construction
Requirement 1: It can only be implemented in new stables

Solution LL18: Slurry acidification
Requirement 1: For in-house acidification: refurbishment of animal house to facilitate slurry acidification in the pre-tank and its recirculation in below-floor channels. Space for the sulfuric acid tank (outside building) and the controller unit (incl. pH sensor) for dosing appropriate amounts of acid. For acidification of outdoor storage tank: availability of contractor with equipment (incl. safety devices) and experience with acidifying animal slurry in storage tanks. For in-field acidification: Refurbished or new manure application tanker that includes a tractor-mounted acid tank, controller unit (incl. in-line pH-sensor), tubing and nozzles which add the acid to the slurry in-line during field application
Requirement 2: Skilled workers trained to operate the equipment and to comply with and respect safety precautions for handling strong industrial acids
Requirement 3: Large-scale supplier of industrial grade sulfuric acid, with a delivery system complying with all safety regulations, at a reasonable economic cost

Solution LL19: Slurry bio acidification
Requirement 1: Availability of organic residue with high contents of easily degradable carbohydrates suitable for microbial fermentation to bioacidify the slurry. Ideally, the organic residue is produced in ample quantities at the farm or locally to avoid excessive transportation costs
Requirement 2: Tank or other types of storage space for the residue. Some types of conservation, e.g. by ensiling, ensuring little loss of substrate quality or emissions of pollutants. Conditioning unit for premixing residue with the slurry in pre-tank or storage tank, pH control unit for monitoring and managing bioacidification.

Barriers and boosters

The barriers preventing implementation and possible boosters for each solution (suitable for pig agrotypology) are reported in Table 5.

Table 5. Pig Agrotypology barriers and boosters

Solution	**Barriers to implementation**	**Possible boosters to implementation**
LL25	Climate conditions are not perfect for all varieties. Land area required. Additional labour. Extrusion equipment is necessary	Research for suitable varieties

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LL45	Competitiveness of legumes versus current feed products. Land area required. Additional Labour Units	Research: suitable legume varieties under different agricultural systems
LL40	High CAPEX and OPEX Area required. Extra labour and skills required. Strict legislation	Support for investment, legislation update, technical support for entrepreneurs
LL41	Investment cost. Area required. Extra labour and skills required	Support for investment, technical support for entrepreneurs
LL41b	Mainly legislation: currently, only plant-based digestate or from ABP cat 3 (excl. catering waste) can be used for feed production, and there is no legislation regarding algae produced on these streams	Legislation update (also supporting more circular recovery (i.e.CO2)) Technical support for small companies
LL24	Capex investment and suitability in new facilities	Information and dissemination, **support for investment**
LL18	Additional costs (CAPEX and OPEX) More work (work hours to monitor in-house or contractor for storage or in-field acidification). Potential danger of handling dangerous acid. Slurries acidified with sulfuric acid can only to a limited extent be utilised in anaerobic digestion plants for the production of biogas	**Legislation update:** Environmental regulations requiring mitigation of ammonia emission from animal production to the atmospheric environment. Stricter field fertiliser N application laws resulting in higher economic value of acidified slurry (if application of acidified slurry is not required adjusted for increased available N content). **Subsidies for implementation**. Coupling with S fertilization: accounting not only for N fertiliser value, but also for substituting S fertiliser from sulfate added with the sulfuric acid
LL19	Extra work and knowledge of the bio-acidification treatment. Insufficient amounts of suitable residues available for bio-acidification. Difficulties and costs of adapting facilities for pH control and residue dosage/storage. Potential negative effects on the N fertiliser value of bio-acidified slurries (due to N immobilisation).	**Legislation:** Environmental regulations requiring mitigation of ammonia emission from animal production to the atmospheric environment. Technical support
LL23	lack of legislation on ReNure high investment costs	Legislation update

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Pig agrotypology reference

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4. Cattle Agrotypology

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Sector outline

Using data collected from the European Union (EU), the total herd size of bovine animals within the EU for 2022 was 76 million. Over 50% of these 76 million populations was found within just four member countries, namely, France (17.5 million), Germany (11.5 million), Ireland (7 million) and Spain (7 million) (Livestock Population in Numbers, 2022). Cattle Agrotypology across the EU produces two main products - dairy products and meat products.

The dairy products produced are varied, from initial raw milk to refined value-added products such as cheese and infant formula. Across the EU, 155 million tonnes of raw bovine milk were produced in the year 2021. Of this total volume, 147 million tonnes were refined by dairy processing companies. The outstanding 8 million tonnes remained at the source farms either to feed dairy calves, feed farmers' families and/or to be used in cottage-industry-style milk processing (Milk & Milk Product Statistics, 2022). In 2021, the three main products produced from bovine milk were whey (56.9 million tonnes per annum), drinking milk (23.2 million tonnes per annum) and cheese (10.4 million tonnes per annum) (Milk & Milk Product Statistics, 2022). Within the same year, the EU dairy industry was estimated to be worth €148 billion (Augère-Granier, 2018). All 27 member countries produce bovine dairy milk, with approximately 75% of all bovine milk produced from 6 of these 27 countries alone, namely, Germany, France, the Netherlands, Poland, Italy and Ireland. The dairy sector is the second largest agricultural sector within the EU, only surpassed in scale by the vegetable/ horticulture agricultural sector, and collectively, the EU's 27 member countries represent the world's largest bovine milk producer (Shahbandeh, 2023). A major factor in the EU's dairy industry growth over recent years has been the abolishment of milk quotas, which took place in 2015. On average, since the abolishment of the quota system, raw milk yield has increased by 0.7 million tonnes per annum across the EU (Livestock Population in Numbers, 2022).

Along with milk production, beef production and, to a lesser extent, veal production is the other main industry associated with the EU cattle Agrotypology. It is estimated that the EU produces 7 million to 9 million tonnes of beef annually (Hocquette et al., 2018; Vinci, 2022) with an approximate annual value of €98 billion. As a result, the collective beef production from the 27 member countries leads to

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the EU being ranked as the third largest beef producer in the world for 2021. There are two streams of beef production within the EU; one stream represents cattle breeds specifically grown for beef production e.g., Hereford, Aberdeen Angus. The other stream uses surplus livestock from the dairy industry to produce beef e.g., Friesian breeds or Friesian-cross breeds. Data collected by the European Parliamentary Research Service demonstrated that within the year 2020 three member countries alone were responsible for 50% of all beef produced within the EU; these three member countries were France, Germany and Italy. In 2021, annual per capita beef consumption was 10.3 kg across the EU. (Vinci, 2022).

How dairy and beef farms are managed varies considerably from farm to farm and from region to region across the EU. The variation is predominantly a result of farm management styles, plus local topography and climate. Within the cattle Agrotypology, such diversity can be seen in a variety of aspects such as chosen grazing systems, breed selection, the extent of concentrate feed use and selected cattle housing types, to list but a few factors. Such variety understandably results in variance in terms of nitrogen, phosphorous and carbon (NPC) nutrient usage and losses from farm to farm and region to region. Nonetheless, this chapter aims to provide information relating to NPC nutrient closure framed within an EU-wide scale.

In Table 6 the main numbers of the sector are reported, while in Figure 4 the share of UAA dedicated to cattle agrotypology and the share of LSU dedicated to cattle agrotypology is reported.

Table 6: Cattle Agrotypology factsheet

Parameter	Unit	Value
Herd number in EU	N	76 Million (Livestock Population in Numbers, 2022).
Turnover	€	Bovine dairy = €148 billion (Augère-Granier, 2018) Bovine beef = €98 billion
Number of companies in EU	N	370,000
Agricultural area dedicated in EU	Ha	102 million Ha (Leip et al., 2015; Farms & Farmland in the European Union, 2022)

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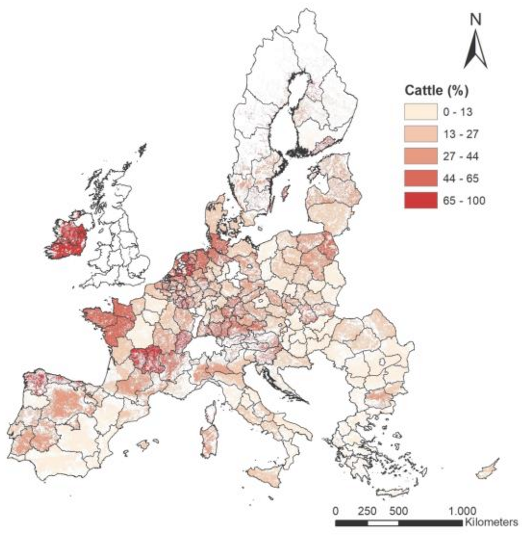

Figure 4 Share of UAA dedicated to cattle agrotypology at NUTS 2 level and share of LSU dedicated to cattle agrotypology. The maps are based on data of the Farm structure survey of Eurostat

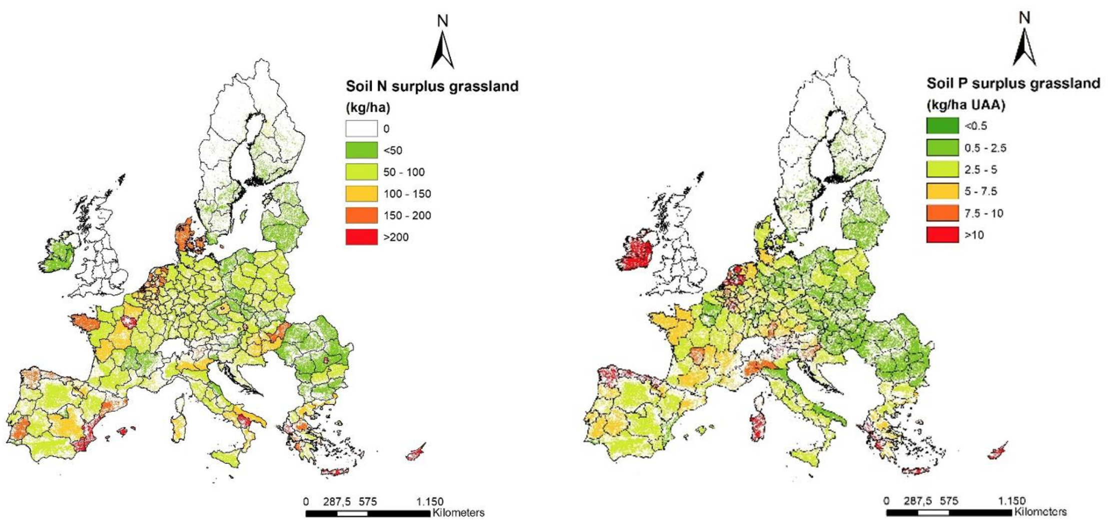

Figure 5: soil N and P surplus in managed grassland (no (semi)natural grassland).

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Problems and challenges related to CNP closure

Nutrient management problems associated with the cattle Agrotypology related to NPC cycles are listed in the table below, along with a qualitative estimation as to the extent of the problem.

Table 7:Extent of the problems related to CNP cycles in cattle agrotypology.

Problem	Extent of the Problem
N Surplus	+
P Surplus	+
NH_3 Emissions	+++
N Leaching	++
GHG	++
NP Dependency from Non-Renewable Source	++
Feed Dependency & Food Security	+
Carbon Depletion/ Soil Degradation/ Fertility Decline	+

+- neutral; no problem
+ minor problem
++ problem
+++ big problem

Several specific problems have been identified within the EU cattle Agrotypology in regard to nutrient use efficiency and nutrient overload. These problems are described below:

i) Loss of Nutrient Value and Release of GHG from Cattle Waste

Ongoing agricultural research indicates that current popular storage systems for cattle slurry and farmyard manure (FYM) across Europe, such as slatted tanks, lagoons and aboveground tanks, are sources of nutrient losses within cattle production systems, particularly losses associated with nitrogen (N) (Kupper et al., 2020). Current legislation enforces farmers to install adequate slurry storage tanks to contain the animal waste during periods when application onto farmland is prohibited (Thieffry, 2022). Primarily, the storage units recommended to farmers are various forms of tanks where the animals' dung and urine are collected and stored together. These tank designs are often open to the air and, excluding covered tanks, are open to rainfall also. As a greater understanding of emissions from cattle slurry develops, challenges associated with current storage systems become more widely understood. By storing the solid fraction of cattle waste (dung) with the liquid fraction of cattle waste (urine) an enzyme within the solid waste called urease can interact with urea present within the liquid waste, which results in the production of ammonia (Byrne et al., 2020). Over half of the nitrogen content found within manure is typically attributed to ammonia. Therefore, losses in ammonia due to the enzymatic degradation of urea can significantly reduce the concentration of N

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within cattle manure. Unsealed storage systems open to the air also result in the uncontrolled release of methane and nitrous oxide into the atmosphere.

ii) Sub-Optimisation of Cattle Waste Nutrient Value

Another nutrient management challenge associated with storing solid and liquid animal waste within the same tank relates to an inability to avail of the natural nutrient concentration found within each waste product. Typically, the nutrient phosphorus (P) is concentrated within the solid waste fraction (dung) and nitrogen (N) and potassium (K) are concentrated within the liquid waste fraction (urine) (*Hjorth et al., 2011*). But, when these waste products are stored together, isolating nutrients of interest is not possible, e.g., a pasture or field may have a high soil P index but a low soil K index and in such a situation access to the liquid fraction of the cattle waste only, could be an attractive option for the farmer, as opposed to sourcing a K rich chemical fertiliser. The loss in nutrient value of the manure via current storage practices and the inability to isolate solid manure from liquid manure fractions could contribute to the cattle industries' reliance on supplementary chemical fertiliser products.

iii) Inconsistency of Cattle Waste Nutrient Value

The availability of nutrients within slurry and farmyard manure is highly variable due to a number of factors (*Teagasc, 2022*). Such variability can contribute to overreliance on chemical fertilisers to meet plant nutritional needs. Slurry/ FYM laboratory analysis can be undertaken but often the most accurate nutritional results require the contents to be agitated prior to sampling to provide a representative sample. This is a further challenge as agitating typically occurs just prior to slurry application onto receiving lands.

iv) Nutrient Overloading

Traditionally, cattle production within Europe involves outdoor grazing i.e., cattle grazing out in the field for a portion of the year as opposed to indoor feeding all year round. While grazing cattle deposits both dung and urine within pastures, it is difficult to factor these nutrient deposits into fertiliser management plans (*Carter, 2007*).

Although farmers and farm advisors recognise N, P, K within the cattle waste products, there are no accepted means of assessing **how much** N, P, K has been deposited **and where it has been deposited** within the pasture. When applying fertiliser onto a recently grazed pasture, there is a risk of nutrient overload within locations that received waste deposits from the grazing animal. It has been shown that N loading within urine patches can exceed 700kg N/ha equivalent, with such patches becoming hotspots for N losses. Excessive nutrient loading can lead to nutrient leaching and the subsequent eutrophication of nearby waterways. Excessive N loading within pastures can also lead to nitrous oxide (N_2O) production. Additionally, nutrient loading can lead to excessive or unnecessary consumption of

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chemical fertilisers, which also results in carbon losses from the system due to the energy spent in manufacturing and transporting the fertiliser, along with losses in N and P depending on the fertiliser product type used. An additional source of nutrient overloading is the excessive application of cattle slurry/ FYM. This is especially prolific in regions with high livestock density and that have a limited application window due to weather e.g. high rainfall regions. Although cattle slurry and FYM are valuable fertilisers, off-loading excess to receiving farms can be difficult due to the costs associated with transporting these organic fertilisers. Therefore, excessive application on grazing land surrounding storage tanks can occur. Excessive application can lead to losses in N and P by both leaching and via losses to the atmosphere.

v) Reliance on Chemical Fertilisers

Figures from Eurostat state that during the year 2020, 10 million tonnes of nitrogen (N) fertiliser were consumed, along with 1.2 million tonnes of phosphorous (P) within European agriculture (Mineral Fertiliser Consumption Remained High in 2020, 2022). Chemical fertilisers possess many attractive qualities such as high plant available nutrition and dependable, precise fertiliser ratios, but Europe is significantly reliant on imported raw materials to manufacture the fertiliser products, such as natural gas and rock phosphate; such raw ingredients are finite in nature. Furthermore, unlike animal slurries and manures, chemical fertiliser can be easily shipped and transported to regions of demand, and different fertiliser products can be used within the boundaries of the Nitrates Directive, where the application of livestock slurry/ manure is limited.

vi) Reliance on the Import of Nutrients in the form of Feed

The use of concentrate feed within the cattle industry is widespread across the EU, with the 27 member countries collectively representing the world's largest importer of livestock feed (*Animal Feed Preparations, 2020*). Concentrate feed represents a supplementary dietary product and supplies the animal with energy, protein and minerals. Within the conventional dairy industry, concentrate feed assists in maintaining both animal health and milk yield. Within the conventional beef industry concentrate feed assists in maintaining animal health and is critical for animal weight gain ('fattening'). Some common ingredients within concentrate feed are often sourced from outside the EU, such as soybean and maize meals. On conventional cattle farms, concentrate feed products are considered critical to productivity and are included in the diets of all animals, including dairy cows, dairy calves, suckler cows, weanlings, heifers and bullocks. Regarding CNP nutrient usage, concentrate feed is associated with energy expenditure due to the level of transportation involved, along with causing land-use changes within source countries such as Brazil. Within the EU, approximately 250 million tonnes of concentrate feed are produced annually (Heuvelmans*, 2017*), but not all EU concentrate feed needs are met from this tally alone. In 2017 the European Commission estimated that 16.7 million tonnes of crude protein were imported into the EU for livestock feed purposes, with approximately 25% to 30% of this volume allocated to the cattle industry (dairy & beef). Analysis carried out by Alltech found that during 2021 Europe experienced a decrease of 1.2% in terms of the volume of feed produced due to several issues such as African Swine Fever, the high cost of raw materials, low prices

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obtained for end-products and the general disruption caused by the Covid-19 pandemic (*Alltech, 2022*).

Furthermore, within Alltech's analysis, it was observed that the volume of feed grown specifically for beef production reduced by 1.9% globally in 2021. The study observed the challenges facing the EU beef industry, especially meeting policy targets such as reductions in gaseous emissions or goals set within such policies as the Feed Sustainability Charter, along with possible changes in consumer diet preferences. At present, within Europe, there is a discrepancy between the amount of native protein produced for cattle feed and the amount of protein required by the agrotypology, and if such decreases in produced feed continue, this discrepancy may become more pronounced. By relying on imported animal feed to ensure the union has enough to meet livestock production needs, goals set within the 2030 Farm to Fork strategy, such as reduced dependence on imported feed, may not be met. Finally, the use of concentrate feed based on soy contributes to a net import of extra EU nutrients in the EU livestock areas, mainly in areas of intensive cattle breeding (non-pasture) such as in Po Valley, generating management problems (nutrient surplus area).

N2C solutions tackling the CNP challenges in cattle agrotypology

Five technologies (innovations) were selected from the original Nutri2Cycle longlist to solve the various NPC nutrient management challenges observed within the cattle Agrotypology system. The Nutri2Cycle solutions able to tackle the main challenges of the sector can act according to the main strategies listed below:

- Decrease Import (DI)
- Increase Export (IE)
- Improve the Efficiency of Nutrient Use (NU)

Table 8: solutions applicable to cattle agrotypology and strategies to tackle the CNP challenges.

LL Number	Title of the Solution	Strategy		
		DI	IE	NU
10	Farm-Scale Anaerobic Digestion			x
11	Recycling Fibres of Manure as Organic Bedding Material for Dairy Cows	x		x
18	Slurry Acidification with Industrial Acids to Reduce NH_3 Volatilisation from Animal Husbandry Systems			x
45	INPULSE – Innovating Towards the use of Spanish Legumes in Animal Feed	x	x	
68	Integration of UAV/ Drone & Optical Sensing Technology into Pasture Systems			x

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i) LL10: Farm-Scale Anaerobic Digestion (AD) - this solution processes cattle feedstock such as raw waste within an oxygen-free environment containing micro-organisms. This refinement results in the production of biogas which can be fed through a combined heat and power unit (CHP) to produce power for the farm or, if more appropriate, can be provided to the national power grid. The process also produces a nutrient-dense digestate that can be used as fertiliser. When operated at full efficiency, models have shown that farm-scale **AD can reduce methane and nitrous oxide emissions from farms by 50%**. Thus, the solution, if correctly implemented, can mitigate GHG emissions ammonia emissions and thus improve and optimise the nutrient value of digested slurry.

ii) LL11: Recycling Fibres of Manure as Organic Bedding Material or Dairy Cows – within this solution, raw cattle waste is separated into liquid and solid fractions by passing the waste through a screw press system. The solid fraction is refined further to produce a safe form of bedding for dairy cows which can be applied within a cubicle housing unit setting. Refining the cattle waste in this way can reduce the volume of surplus waste and the need to consume virgin raw materials such as straw.

After the solid waste has been spent as a bedding material, it remains rich in organic matter and can be used as a soil conditioner. The separated liquid fraction contains high concentrations of N and K, which can be applied to the land, increasing nutrient efficiency.

iii) LL18: Slurry Acidification with Industrial Acids to Reduce NH_3 Volatilisation from Animal Husbandry Systems – this solution proposes to reduce gaseous emissions (ammonia, methane, nitrous oxide) from cattle waste by lowering the pH of the waste, ideally to a pH of 5.5. Sulphuric acid is used to achieve this lowered pH, and there are two associated nutrient benefits. Firstly, under a lower pH less nitrogen is lost from the stored waste in the form of ammonia emissions as under these pH conditions, the proportion of ammonia within the waste is reduced and the proportion of the more stable ammonium ion increases. Secondly, by reducing these emissions, the nutrient value of the slurry itself increases. Ammonia emissions can be decreased by >90% from the entire animal slurry management chain. In addition, nitrous oxide emissions can be reduced by 50% – 90% and methane emissions by up to 90%.

iv) LL45: INPULSE – Innovating Towards the use of Spanish Legumes in Animal Feed – this solution aims to reduce the current reliance on imported cattle feed protein, and, to develop an understanding of the appropriateness of different legume varieties within varying farm management systems. Further aims of INPULSE are to improve the overall diversity and sustainability of the EU food chain. Further propagation of legumes within the agricultural industry may also reduce the need for nitrogen fertiliser applications, given the N-fixing quality of leguminous plants.

v) LL68: Integration of UAV/ Drone & Optical Sensing Technology into Pasture Systems – this solution aims to address challenges relating to nutrient overloading and losses of nutrients in terms of emissions and leaching when applying cattle waste onto grazed pastures. Utilising drone and optical sensing technology can detect dung and urine patches within recently grazed pastures. It has been

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shown that N loading within urine patches can exceed 700kg N/ha equivalent, with such patches becoming hotspots for N losses within the system in the form of ammonia, nitrous oxide and N leaching. On trial grazing sites approximately 20% of the recently grazed paddock area is allocated to urine/dung patches. This results in a 20% reduction in applied N fertiliser but no expected reduction in grass yield. By avoiding N application onto urine/dung patches, N nutrient loops are closed further as less N fertiliser is applied and the risk of N losses from the paddock reduces i.e., reduced risk of excessive N loading.

Requirements for applicability

The specific requirements for the applicability of each solution at the farm level are listed in the tables below.

Table 9: Requirement for implementing solutions in cattle agrotypology

Solution LL10: Farm-Scale Anaerobic Digestion
Requirement 1: Suitable herd size, approximately 80 cows minimum
Requirement 2: Planning permission for constructing anaerobic digestor plant
Requirement 3: Connection to national power grid or connection to on-site combined heat and power unit to generate power from biogas produced
Requirement 4: Appropriate land area on which to apply the nutrient-rich digestate (same as for slurry)
Solution LL11: Recycling Fibres of Manure as Organic Bedding Material for Dairy Cows
Requirement 1: Access to housed dairy cows i.e., cubicle housing system for manure handling
Solution LL18: Slurry Acidification with Industrial Acids to Reduce NH_3 Volatilisation from Animal Husbandry Systems
Requirement 1: Access to entire slurry management chain i.e. access to slatted housing units, external slurry storage tanks and in-field slurry spreading tanks.
Requirement 2: Access to sulphuric acid, approximately 6-8 kg of sulphuric acid required per m^3 of livestock slurry in order to achieve optimum pH of 5.5
Requirement 3: Equipment to gauge/ test livestock waste pH value
Solution LL45: INPULSE – Innovating Towards the use of Spanish Legumes in Animal Feed
Requirement 1: Access to appropriate land area
Requirement 2: Access to a variety of legume breeds
Solution LL68: Integration of UAV/ Drone & Optical Sensing Technology into Pasture Systems
Requirement 1: investment in tech and skilled staff

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Barriers and boosters

The barriers and boosters for implementation of each solution are reported in **Error! Reference source not found.**.

Table 10: Barriers and boosters for solutions applicable in cattle agrotypology

Solution	Barriers to Implementation	Possible Boosters to Implementation
LL10	Financial Costs (Investment Costs); Competitiveness & Efficiencies of Farm-Scale Plant versus Large-Scale Plant. Future Prices or Subsidies Allocated to Produced Biogas/ Energy. Skillset Required; Additional Labour Units; Planning Permission.	Support to investment or Premium Biogas/ Energy Prices.
LL11	Initial investment Additional Labour needed in the farm	Mild support to investment, legislation update that somehow prioritize recovered bedding over virgin material
LL18	Skillset required. Additional Labour Units.	Information and technical support.
LL45	Competitiveness of Legumes versus Current Feed Products; Land Area Required; Knowledge Relating to Optimal Legume Variety for Given Regions/ Agricultural Systems; Additional Labour Units.	**Research** on suitable varieties.
LL68	Skillset Required; Equipment Required; Additional Labour Units.	Information and technical support.

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5. Poultry agrotypology

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Sector outline

The poultry sector in the European Union is a significant contributor to the region's economic outcome (meat and egg production). In 2021, the sector comprised over 367 million laying hens and 7.2 billion broilers, making EU one of the largest producers of meat and eggs worldwide. Poultry production in the EU is dominated by chickens, which account for 82% of total production, followed by turkeys (13%), ducks (3.5%), and other species (1.5%) (AVEC, 2021).

In terms of consumption, the annual consumption of poultry meat in the EU was 15 million tons in 2021. The highest meat production was recorded in Poland (17%), followed by the UK (13%), France (11%), Spain (11%), Germany (10%), Italy (9%), and Hungary (4%) (Rosemarin et al., 2021). In addition to meat, laying hens in the EU produce over 6.7 million tons of eggs annually (European Commission, 2021). Cage breeding is the dominant mode of breeding in the EU, accounting for 49.5% of total production, followed by bedding (32.5%), free-range (11.8%), and organic breeding (6.2%) (KIPDiP, 2017; Otwarte klatki 2021).

The intensive poultry production in the EU generates significant amounts of manure, which poses a challenge in terms of handling, managing, and processing this type of waste. In 2021, animal manure production in the EU exceeded 1.8 billion tons, with poultry contributing to 30% of this amount (0.54 billion tons) (Rosemarin et al., 2021).

Table 11:Poultry Agrotypology factsheet

Parameter	Unit	Value
Herd number in EU	n	a) More than 367 mln laying hens in 2021 b) 7.2 mld broilers in 2018.
Turnover	€	38 billion euros of value in poultry meat production in the EU.
Number of companies in EU	n	In EU 25,000 family farms located mostly in rural areas. In 2022 in Poland 2184 poultry farms.
Agricultural area dedicated in EU	ha	The "average European livestock farm" uses 34 hectares of agricultural land area and has a herd size of 47 livestock units.
Agricultural area with nutrient surplus	%	The overuse of chemical fertilizer in cropping systems caused that 30% – 60% of the N applied was lost to the environment.

To frame the breadth of the sector in Figure 6 is reported the share of UAA dedicated to poultry agrotypology (feed for) at NUTS 2 level and share of LSU dedicated to poultry agrotypology.

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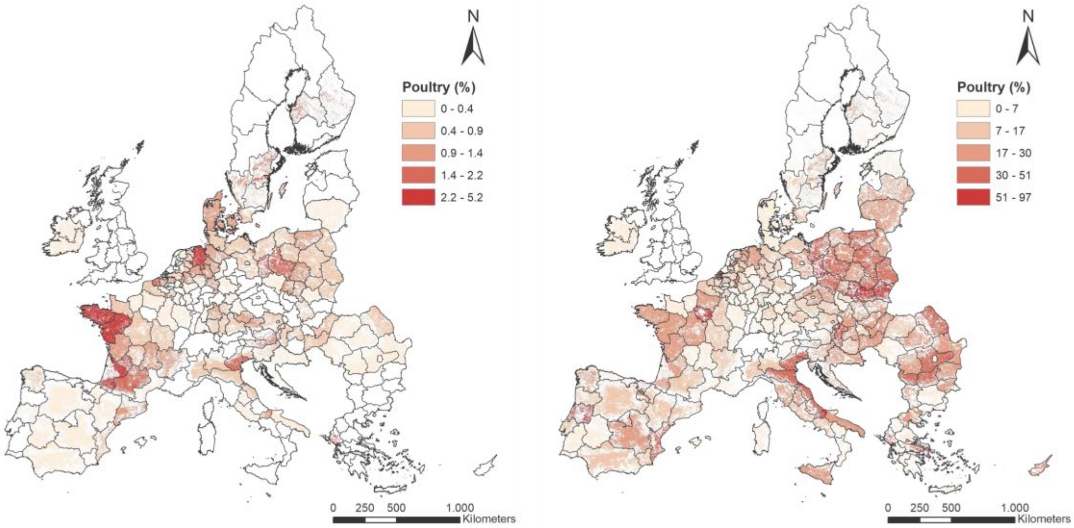

Figure 6: Share of UAA dedicated to poultry agrotypology (feed for) at NUTS 2 level and share of LSU dedicated to poultry agrotypology. The maps are based on data of the Farm structure survey of Eurostat

Processing methods which allow conversion of poultry manure to value-added products with high fertilizing potential can include drying, composting and pyrolysis. These methods allow the conversion of raw poultry manure into stable materials which can be easily stored, transported, and distributed in the agricultural fields. With the introduction of new legislation on fertilising products (i.e., Fertilizing Product Directive from July 16, 2022) it is expected that the interest in such resources as poultry manure to be used as substrates to obtain e.g., soil organic enhancers will increase.

Poultry manure-based soil enhancers could – after fulfilling the conformity assessment – become available on the EU market. This opens more possibilities for the countries with high poultry production, and thus significant quantities of poultry manure to be managed and treated.

Problems and challenges of the sector related to the CNP closure

Nutrient management problems of the poultry agro typology related to NPC cycles are listed in the table below, along with a qualitative estimation of the extent of the problem.

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Table 12: Extent of the problems related to CNP cycles in poultry

Problem	Extent of the problem
N surplus	+++
P surplus	++
NH_3 emissions	+++
N leaching	+++
GHG	+++
NP dependency from non-renewable source	-
Feed dependency and food security	++
Carbon depletion/soil degradation/ fertility decline	-

- no problem
+ minor problem
++ problem
+++big problem

In detail a description of the major challenges the sector faces for CNP closure

i) Reliance from external feed and nutrient overload: Intensive production of poultry is linked, as for the other livestock agrotypology (pig), to significant import of feed, the production of large amounts of by-products, mainly litter and poultry manure that cause nutrient concentration in specific areas.

ii) air emissions from stable and storage: The amount of ammonia (NH_3) released from poultry manure from laying hens ranges from 2 to 20% of the total nitrogen excreted by the animal, while for broilers it ranges from 13-20% of the total excreted nitrogen (Dróżdż et al., 2020). Also, high levels of ammonia above 25 ppm in a poultry house can cause decreased appetite in animals, slower weight gain, generated oxidative stress, respiratory problems, aches and pains, and inflammation of the eyes (Swelum et al., 2021).

Storing poultry manure also generates a loss of ammonia in the atmosphere and soil. Total nitrogen loss from poultry manure storage ranges from 13 to 30%. Depending on the season, storage method, poultry breed, nutrition, and external factors, such as temperature and humidity (Chastain et al., 1999). Storage of poultry manure on the farm in an uncovered area generates losses of 21% of TAN, which can be reduced by 13% when manure is covered and further decreased by storing manure in closed containers and facilities (Lesschen et al., 2021).

The other risks associated with the lack of proper management of poultry manure are emissions of odour and other gases such as CH_4, N_2O, H_2S, NO_x carbon monoxide, PM 2.5, and PM10 dust.

iii) metals: It is also worth paying attention to the quality of poultry nutrition because poultry manure can contain significant amounts of zinc and copper, which are used to improve poultry resistance to disease. Just to give an order of magnitude, comparing poultry manure with cattle manure, it turns out that in poultry the concentration of excreted zinc is 427 mg/kg, while in cattle manure only 150 mg/kg (Wieremiej 2017; Tańczuk et al., 2019; Dróżdż et al., 2020).

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Table 13: Quantities of emitted gases and dust from poultry breeding.

Compound emitted into the atmosphere	Quantity of compounds	Type of breeding and number of poultry	References
Ammonia – NH_3	0.1-0.4 kg/year	From 1 broiler	EIP, 2018
Methane – CH_4	0.08 kg/year	From one-layer hens	Dróżdż et al., 2020
Nitrous oxide – N_2O	0.02-0.25 kg/year	From one-layer hens	Koerkamp et al., 2008; Agrotech, 2011; Broucek, 2018
	0.01-1.39 kg/year	From 1 broiler	
Sulfur dioxide – SO_2	15-60 g/kg	Per kg live weight broiler	Ogino et al., 2021
Carbon monoxide – CO	0.0007-0.0035 m^3/h	From 1 broiler	Canadian Poultry, 2012
Carbon dioxide – CO_2	0.17-0.52 kg/year	From one-layer hens	Broucek, 2018; AgroTech, 2011
	0.68-2.94 kg/year	From one broiler	
$PM_{2.5}$ dust	0.0008 kg/year	From 1 broiler	Bip, 2020
PM_{10} dust	0.004-0.025 kg /year	From 1 broiler	

iv) Microbiological risks: Incorrect management of poultry manure also poses a risk of microbiological contamination of water or soil by bacteria, e.g. Escherichia coli, Salmonella, and Listeria. Significant amounts of antibiotics (e.g., Tetracyclines), pesticides, insecticides (e.g., Fipronil), and growth hormones (e.g., endocrine-disrupting compounds-EDCs) can also be found in poultry manure (Tańczuk et al., 2019; Dróżdż et al., 2020).

N2C solutions tackling the CNP challenges

Five innovative solutions were selected from the original Nutri2Cycle longlist as solutions to the various CNP nutrient management challenges observed within the poultry agrotypology system. The Nutri2Cycle solutions are able to tackle the main challenges of the sector according to the main strategies listed below:

- Decrease import of nutrient (DI)
- Increase export of nutrients (EX)
- Improve the efficiency of the nutrient use (NU) decreasing impacts

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Table 14: Solutions applicable to Poultry Agrotypology and strategies to tackle the CNP challenges

LL number	Title of the solution	Strategy		
		DI	EX	NU
48	Recovery of energy from poultry manure and organic waste through anaerobic digestion		x	x
27	Use of an inoculate of microbiota and enzymatic pre-cursors to reduce ammonia emissions and optimize nutrient use efficiency in poultry manure			x
47	Production of growing substrates for horticulture application from poultry manure, solid state digestate and biochar through composting		x	
40	Insect breeding as an alternative protein source on solid agro-residues (manure and plant wastes)	x		
25	Soybeans in Poland - innovative solutions in the cultivation, plant protection and feeding on farms	x		

Solution 48: The solution aims to increase the efficiency of the anaerobic digestion of sewage sludge and poultry manure. Poultry manure can be successfully introduced into digesters at a wastewater treatment plant. Such synergy allows not only to increase biogas production in a significantly statistic way, but also VS removal. Moreover, the introduction of the manure together with the feedstock does not destabilize the operation of the digesters. It hence creates a new potential place for alternative treatment of organic industrial waste such as poultry manure. Using poultry manure itself as a substrate for anaerobic fermentation makes it very difficult to maintain a proper process, through significant ammonia concentration. This solution provides a unique opportunity for wastewater treatment plants to improve their profitability by enhancing energy recovery from sludge and full utilisation of the existing infrastructure.

The solution also addresses the need of proper storage and handling and increase the efficiency of nutrient delivery to soil and help decreasing GHG emissions (methane and N_2O). Moreover it is an effective solution for the stabilisation and sanitization of the poultry manure, thus addressing the microbiological risk.

Solution 27: Use of an inoculate of microbiota and enzymatic pre-cursors to reduce ammonia emissions and optimize nutrient use efficiency in poultry manure. The solution addresses the problems by **decreasing** ammonia emissions: the N contained in the manure is fixed in the soil thanks by the microbial product and will not be lost as ammonia. In addition, the N will be in a form available to the plant. Moreover, the presence of lactic bacteria in the mixture causes a lowering of the pH with great control of pathogenic microorganisms.

Solution 47 (Production of growing substrates for horticulture application from poultry manure, solid-state digestate and biochar through composting) converts the biodegradable material of poultry manure, into organic soil enhancers and growing media, such as dry poultry manure, poultry manure-derived biochar, compost to enhance soil properties and increase the plant yield. Conversion of

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poultry manure into organic soil enhancers includes composting, pyrolysis, and drying. The solution promotes the export of nutrient and the increase of nutrient efficiency.

Solution 40 Insect breeding as an alternative protein source on solid agro-residues (manure and plant wastes). Insect larvae are reared on manure recovering in a short cycle Carbon, Nitrogen and Phosphorus to be used as local feed. The solution decreases the import of feed and the emissions to the environment respect to the distribution on land (mainly in nutrient-surplus area)

Solution 25 Soybeans in Poland - innovative solutions in the cultivation, plant protection and feeding on farms. The main goal of this study was to increase the possibility of effective domestic cultivation of soybeans in Poland, hence decreasing transport and a more sustainable soybean use in Poland. Moreover, the investigation aims were to increase the nutrition efficiency of livestock through proper techniques of soybeans treatment. For reducing the losses of nutrients, mature soybeans, and soybean waste, which were not used in industrial processes, were used for animal feed. This solution decreases the import of feed, improve food security and decrease the nutrient overload.

Requirements for applicability

The specific requirements for the applicability of each solution at farm level are listed in Table 15

Table 15: requirements for implementing solutions in Poultry Agrotypology

Solution 48
Requirement 1 poultry supply should be within 10-20 km distance
Requirement 2 Legal permits for construction and use.

Solution 47
Requirement 1 composting of digestate and biochar. both should be available, i.e. initial capital investment is needed

Solution 40
Requirement 1 Capital to invest
Requirement 2 energy availability, at least thermal
Requirement 3 high skilled staff to follow the process

Solution 27
Requirement 1 Depending on the type of poultry farming, the amount and type of inoculate of microbiota and enzymatic pre-cursors will be different.
Requirement 2 Determination of the efficiency (e.g., in percent/kg) of using inoculate of microbiota and enzymatic pre-cursors to reduce ammonia emissions.
Requirement 3 Calculation of the profitability of the solution on the scale of a poultry farm.

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Solution 25
Requirement 1 Specify the type of fertilizer that was used to ensure the correct balance of C, N, P and K. So that the solution can be applied to other farms.
Requirement 2 Characteristics of the soil that is used to carry out the soybean growth test.
Requirement 3 Required area for cultivation and agricultural equipment.

Barriers and possible booster for implementation

In the following table are listed the main barriers to the implementation of the identified solutions and some possible boosters.

Table 16: Poultry Agrotypology barriers and boosters

LL	Barriers	Possible booster
48	Capital investment for the facility	Support to investment, technical support
47	Capital investment for the facility	Access to credit, good affordable certified carbon credit scheme for biochar
40	High capital needed	access to credit
27	Low information available from authoritative and independent source	Information and dissemination activities
25	The barrier is the lack of information	Information and dissemination activities

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

6. Cereals and maize

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Sector outline

Core to the food security objective is the production of cereals across the globe to meet the increasing demands for food, animal feed and biofuels. In the EU, the cereals sector accounted for approximately 11 % of the total output value of agricultural production in 2016, third in line after the vegetable/horticultural and the dairy sectors. It is an important sector for many Member States, particularly the northern ones, where it is well developed. All Member States produce some combination of cereal crops (Kelly 2019).

Cereals account for 31% of the total utilizable agricultural area (UAA), so an area of about 48.67 million ha. The main producing country is France, which has the most extensive cereals area, accounting for 17 % of the EU total. It is followed by Poland (14 %), Germany and Spain (both 11 %). Common wheat, maize and barley represent the biggest share (79 %).The country with the highest arable land area compared to total area in Europe is Denmark (59.80%), while this number is the lowest in Montenegro (0.68%).

In Figure 7 is reported the Arable land share as percentage of total UAA, together with soil N and P surplus in arable land

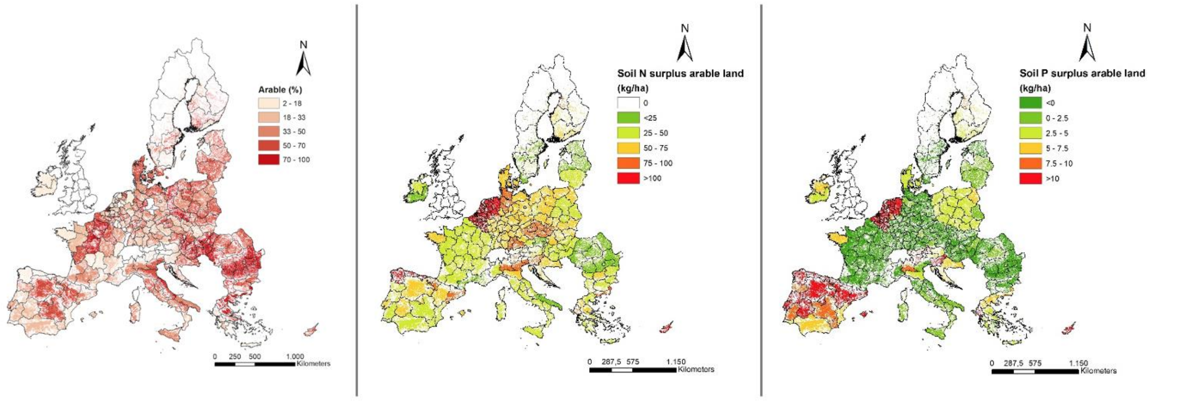

Figure 7: Arable land share as percentage of total UAA at NUTS 2 level (based on Farm Structure Survey of Eurostat), soil N and P surplus in arable land (D1.5, https://edepot.wur.nl/547940) .

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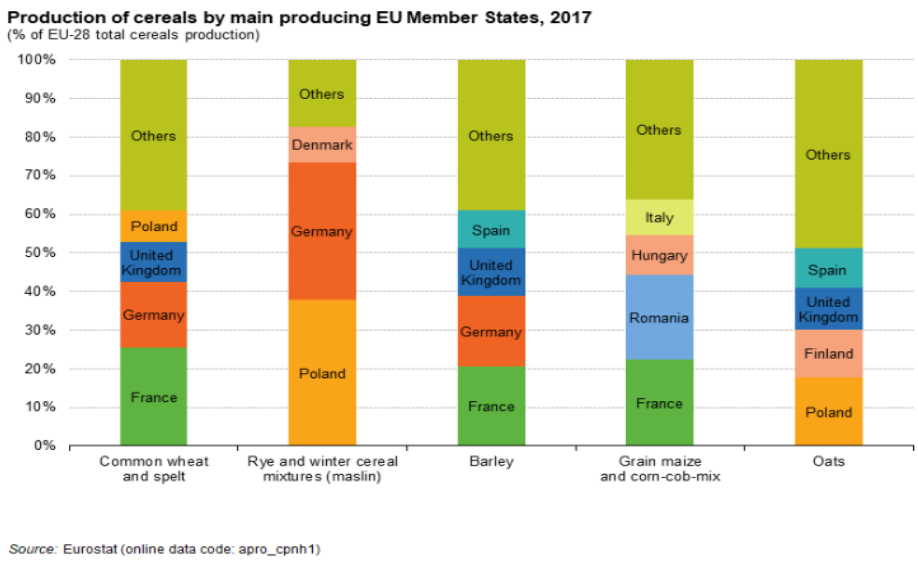

Figure 8: production of cereals by state

More than half of cereals grown in the EU are wheat. The remaining 50% is composed of maize and barley, each representing about one third. The last third includes cereals grown in smaller quantities such as rye, oats, triticale and spelt. The EU's cereals are mostly used for animal feed (nearly two thirds); one third is directed at human consumption, while only 3% is used for biofuels (EU commission). The yearly total EU cereals production is about 286.4 million tonnes (World -grain)

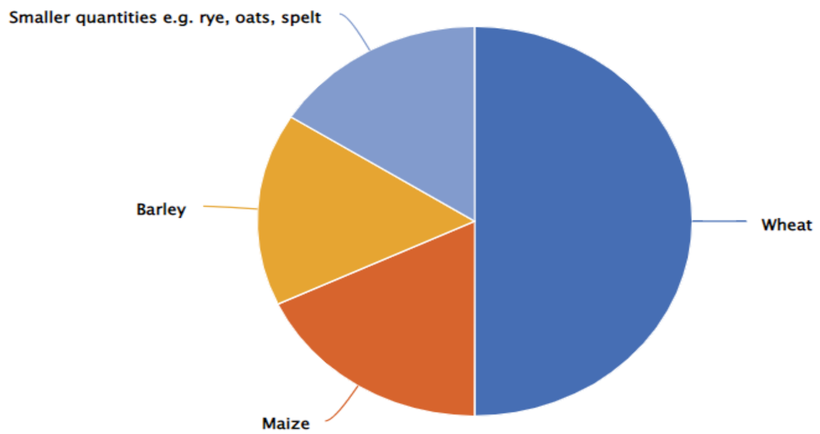

Figure 9: Share of main cereals in the EU (% of total cereals production)

Table 17: Cereals and maize Agrotypology factsheet

Parameter	Unit	Value	Source

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Turnover	€	> 1 trillion	Smartagrihubs
Number of companies in EU	n	-	
Agricultural area dedicated in EU	ha	48.67 million	Kelly 2019

Problems and challenges of the sector related to the NPC closure

As already mentioned, the cereal and maize agrotypology has different problems related to CNP closure respect to the livestock agrotypologies, and mainly are more related to chemical fertilisers dependency and increasing the efficiency of recovered ones (i.e. slurry derived materials that can be imported from nearby livestock areas). The main challenges the sector is facing, can be described as follows:

Increasing demand and pressure for high yield: The world population is still growing, and it is expected that there will be at least 9 billion people on the planet by 2050. Ensuring feed and food security will be an ongoing issue.

High price of energy and fertilisers, increasing competition from outside the EU and lower income of farmers: The need for high yield, low costs and the volatility of the market because of worldwide 'concurrence' in the cultivation of cereals and maize produce as consequences lower production margins and variability in income.

Environmental sustainability, climate change and crop yield: Increasing mineral fertiliser prices force farmers to look for alternative fertilisation strategies. Several regions have a lot of animal manure available that could be used as a mineral fertiliser replacer. However, due to the Nitrates Directive, the amount of animal manure that can be applied on the field is limited to 170 kg N/ha. This paradoxical situation can be encountered by recovering valuable nutrients from animal manure and making them accessible in the form of RENURE (REcovered Nitrogen from manURE) products. These products have a lot of potential to be applied as mineral fertilisers but are up to date still considered as animal manure.

Climate change is causing an increase in the frequency of extreme weather events, whether it is precipitation, temperature, or unusual winds. For agriculture, this usually results in reduced yields and greater variability of these. Changing weather conditions also demand crop varieties that can resist diseases.

Soil quality: some soils in cereal areas in the EU suffer from sub-fertility due to several causes including shorter rotations, decreased use of organic options, excessive nitrogen inputs and deep ploughing. Deep ploughing is associated with disruption to microbial life in the soil and, thereby the synthesis of nutrients available to the plants. In 2008, the Commission estimated that 45 % of European soils had

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a very low organic matter content, with less than 2 % organic carbon in southern European countries, but also in France, the United Kingdom, Germany and Belgium.

In this larger frame, the problems related to NPC cycles of this agrotypology are reported in Table 18 with a qualitative estimation of the extent.

Table 18. extent of the problems related to CNP cycles in Cereals and maize Agrotypology

Problem	Extent of the problem
N surplus	-
P surplus	-
NH_3 emissions	++
N leaching	++
GHG	++
NP dependency from non-renewable source	+++
Feed dependency and food security	-
Carbon depletion/soil degradation/fertility decline	+++

- no problem
+ minor problem
++ problem
+++big problem

N2C solutions tackling the NPC challenges

Within N2C, eight solutions were identified as specifically able to tackle the main challenges that the ‘cereals and maize’ sector is facing. The solutions act according to the main strategies listed below:

- Improve the efficiency of the nutrient use (NU), mainly working on the challenges related to NH_3 emissions, N leaching and GHG.
- Import of recovered CNP from other areas or sectors (I) such as the recovery of NP from livestock wastes

Table 19: solutions applicable to the Cereals and maize Agrotypology and strategies to tackle the CNP challenges

LL number	Title of the solution	Strategy	
		I	NU
30	Precision farming coping with heterogeneous qualities of organic fertilizers in the whole chain		x
28	Precision farming and optimised application: unter-root application of liquid manure for maize and other row crops		x
63	Precision fertilization of Maize using organic materials		x
13	Sensor technology to assess crop N status		x
1	Ammonium stripping / scrubbing and NH_4NO_3 as substitute for synthetic N fertilizers	x	x

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2	Ammonium stripping / scrubbing and NH_4SO_4 as substitute for synthetic N fertilizers	x	x
6	Concentrate from vacuum evaporation/ stripping as nutrient-rich organic fertilizer	x	x
9	Liquid fraction of digestate as a substitute for mineral N & K fertilizer	x	x

- LL30, LL28, LL63 and LL13 Precision farming - Precision farming is a management approach that focuses on (near real-time) observation, measurement, and responses to variability in crops, fields and animals. It can help increase crop yields and animal performance, reduce costs, including labour costs, and optimise process inputs. All of these can help increase profitability. At the same time, precision farming can increase worker safety and reduce the environmental impacts of agriculture and farming practices, thus contributing to the sustainability of agricultural production. Within the presented solutions, precision fertilisation is an important aspect, increasing the nutrient use efficiency, resulting in more homogeneous crop yields and reducing the fertilizers' costs.

- LL1, LL2, LL6 and LL9 Substitution of mineral fertilisers by biobased products – These solutions are all linked to the introduction of biobased fertilizers instead of mineral ones, which can close nutrient loops at farm level. These biobased fertilisers often have the same characteristics as its mineral counterpart but highly contribute to a circular economy by limiting the need to produce mineral N via the energy consuming Haber-Bosch process and to import mined fertilisers (like P). Currently (January 2023), these kinds of products are still considered as animal manure, and as such needs to comply with the Nitrates Directive. However, during several field trials their agronomic and environmental value was already proved. These solutions are able to reduce fertiliser costs for farmers.

Requirements for applicability

The specific requirements for the applicability of each solution at farm level are listed in the tables below.

Table 20. requirement for implementing solutions in Cereal and maize Agrotypology

LL30 Precision farming coping with heterogenous qualities of organic fertilizers in the whole chain
Requirement 1 Technical knowledge and training to use the NIR Sensor correctly
Requirement 2 Availability of sensor equipment or contractors in the region

LL28 Precision farming and optimised application: unter-root application of liquid manure for maize and other row crops
Requirement 1 Availability of equipment for application or contractors in the region

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Requirement 2 Availability of manure close to the fields and farm

LL63 Precision fertilization of Maize using organic materials
Requirement 1 Availability of organic materials (manures) close to the fields and farm
Requirement 2 Availability of equipment for application or contractors in the region

LL13 Sensor/drone technology to assess crop N status
Requirement 1 Investment in technology
Requirement 2 Technical skills in farm or as 3rd party and IT service provider f to prepare the fertilisation maps based on the NDVI maps

LL1 Ammonium stripping / scrubbing and NH_4NO_3 as substitute for synthetic N fertilizers
Requirement 1 The fertiliser equipment needs to be adapted to the product properties
Requirement 2 Monitoring of every batch is important, since the concentration of the product is not always constant
Requirement 3 The product needs to be injected

LL2 Ammonium stripping / scrubbing and NH_4SO_4 as substitute for synthetic N fertilizers
Requirement 1 The fertiliser equipment needs to be adapted to the product properties
Requirement 2 Monitoring of every batch is important, since the concentration of the product is not always constant
Requirement 3 The product needs to be injected

LL6 Concentrate from vacuum evaporation/ stripping as nutrient-rich organic fertilizer
Requirement 1 an injection device is needed

LL9 Liquid fraction of digestate as a substitute for mineral N & K fertilizer
Requirement 1 The product needs to be injected

Barriers and possible boosters for implementation

In Table 21 are reported some barriers that may prevent the implementation of the solutions and some possible boosters.

Table 21. barriers and boosters for solutions in Cereal and maize Agrotypology

Solution	Barriers to implementation	Possible boosters to implementation
LL30	Farmers acceptance to use organic materials. Legislation of some regions. Costs associated with the NIR Sensor (investment costs, signal costs, training cost…)	High mineral fertilizer prices. Need to increase soil organic matter content. information and dissemination activities
LL28	Farmers acceptance to use organic materials. Legislation of some regions. Lack of enough organic materials.	High mineral fertiliser prices and the higher necessity for farmers to substitute mineral fertiliser with alternatives such as manure.

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	Relevant only for maize and other row crops so far	Need to increase soil organic matter content
LL63	Farmers acceptance to use organic materials. legislation of some regions. lack of enough organic materials;	High mineral fertilizer prices. Need to increase soil organic matter content. Need of alternative to mineral fertilizers
LL13	Investment costs. Computing tools and software. Availability of service providers; Reliable data quality. Processing large number of data, pictures temporal and spatial resolutions e.g. the satellite system used by sensors have a large resolution compared with drones' smooth resolution. The interoperability (compatibility) of different systems and the required periodic recalibration of the tools.	Available state aid for the investments. Legal requirements as greening. Environment protection subsidies. Combination of the drone technologies with the auto drive tractor system. Multiple utilisations of the provided maps e.g. pesticides utilisation, precision seeding
LL1	Ammonium nitrate is considered as animal manure, and as such it needs to comply with the Nitrates Directive. Adapted machinery might be necessary. The product content is not constant	legislative update High mineral fertilizer prices
LL2	Ammonium sulphate is considered as animal manure, and as such it needs to comply with the Nitrates Directive. Adapted machinery might be necessary. The product content is not constant	Legislative update High mineral fertilizer prices
LL6	High variability in the nutrient's composition due to variation in the feedstock. Improper characteristics (pH, nutrient ratios, etc.) of the recovered products for a specific crop. Limits on application (i.e. type, rate and method) due to the fertilizer legislation at EU and national level	Legislative update High mineral fertilizer prices
LL9	High variability due to variation in the feedstock of the anaerobic digestion process. To prevent ammonia volatilisation, timing of application is very important. Digestate derived products are considered as animal manure (as long as the digester is being fed with animal manure), and as such they need to comply with the Nitrates Directive	High mineral fertilizer prices. High N minimum content. Compliments Circular Economy Goals

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Eip Agri, https://ec.europa.eu/eip/agriculture/en/digitising-agriculture/developing-digital-technologies/precision-farming-0

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7. Vegetable agrotypology

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Sector outline

The horticulture sector in the EU comprises fruit, vegetables, potatoes, salads, herbs and ornamentals, and incorporates annual and perennial nurseries, retailers, florists and landscape gardening. In general, the fruit and vegetables sector receives about 3% of Common Agricultural Policy (CAP) aid accounting for 18% of the total value of agricultural production in the EU. This represents 3% of the EU usable agricultural area and is worth more than **EUR 50 billion**. The horticulture sector in EU-27 accounts for about 13.7% of the agricultural output which is nevertheless only a small percentage of the total acreage (around 3%). The main annual and perennial vegetable crops are for example tomato, pepper, cabbage, cauliflower, broccoli, carrot, celery, onion, and potato which have as edible products roots, tubers, shoots, stems, leaves, fruits and flowers. (3).The vegetable cropping systems as in general the horticultural systems are intensive in terms of investment, labour requirements and other inputs and are often developed at smaller plots and on quality land. Vegetable farms usually have a higher value per hectare than crops grown in less intensive systems. (2) (5).

In 2013 the total EU vegetable holdings were approx. 920.000, Romania had the highest proportion of vegetable holdings in the EU at 21%, followed by Poland at 15%, Spain at 12%, Lithuania at 10%, Italy at 9%, Bulgaria at 7%, and the remaining EU states at 27%. The largest area dedicated to vegetable crop production in the EU are in Italy (19%), Spain (16%), Poland (11%), France (11%), Romania (7%), and the other EU countries (34%).

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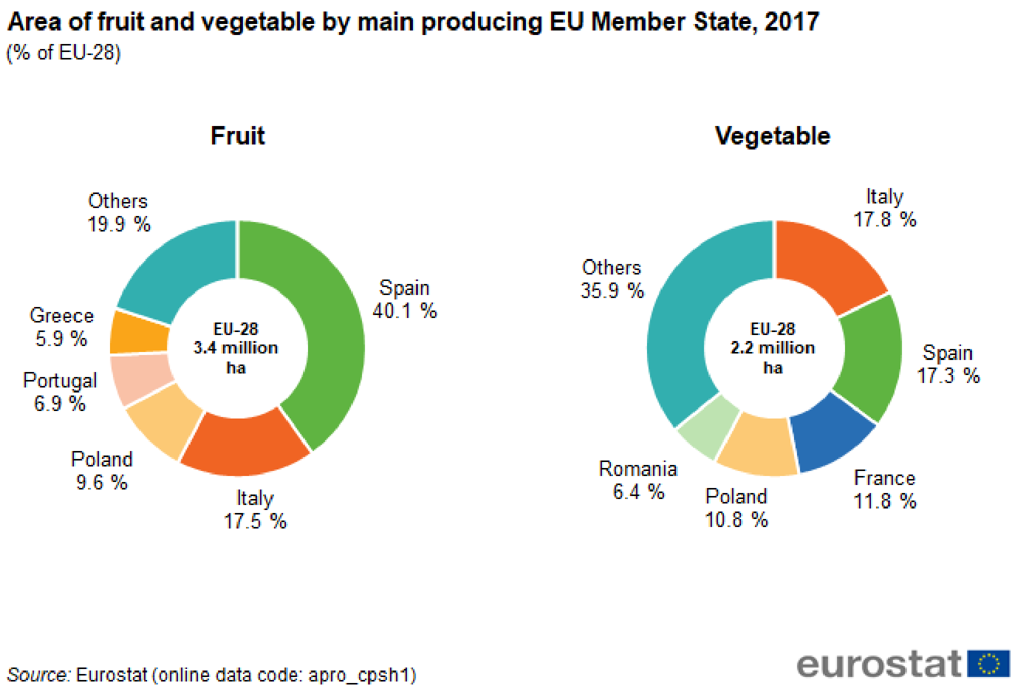

Figure 10. distribution of vegetable production in the EU

Table 22: Vegetable Agrotypology factsheet

Parameter	Unit	Value
Turnover	€	50 billion
Number of companies in EU	n	920.000
Agricultural area dedicated in EU	ha	4.8 million

In Figure 11 is reported the share of UAA dedicated to vegetables and the load of N and P in that share.

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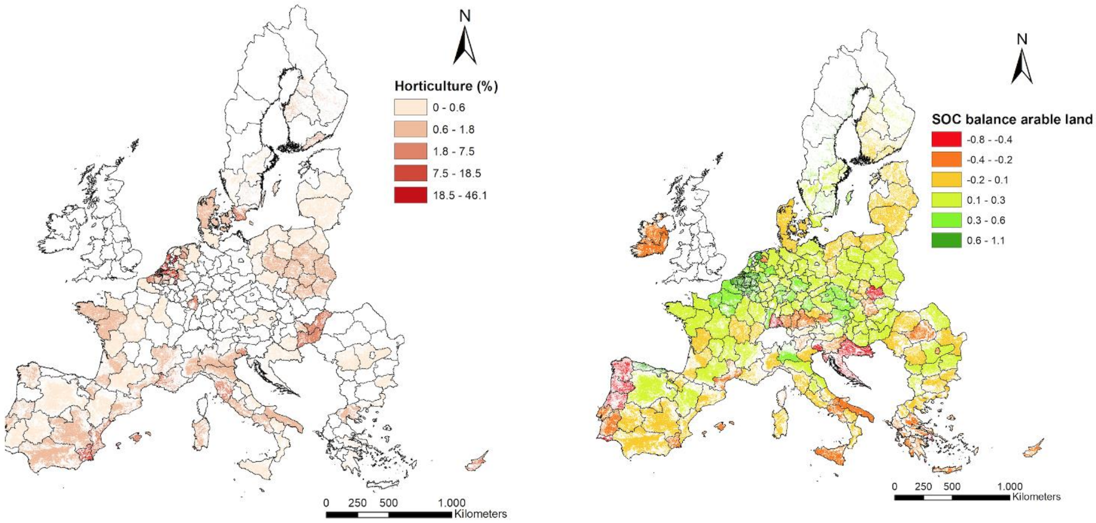

Figure 11: Share of UAA dedicated to horticultureat NUTS 2 level and organic carbon balance of arable land. N2C elaboration.

Problems and challenges of the sector related to the NPC closure

The general problems related to NPC cycles of this agrotypology are reported in Table 23, with a qualitative estimation of the extent. Even if some areas of the vegetable agrotypology may be in the middle of nutrient surplus areas (Flanders, Netherland), the problem of surplus does not arise specifically from this agrotypology, thus is not addressed here, as livestock agrotypologies largely dealt with this topic. Opposite a trend of depletion of carbon in soils is spotted out overlapping areas dedicated to vegetable agrotypology and SOC (Soil Organic Carbon) balance (Figure 11).

Table 23: extent of the problems related to CNP cycles in Vegetable Agrotypology

Problem	Extent of the problem
N surplus	-
P surplus	-
NH_3 emissions	+
N leaching	++
GHG	++
NP dependency from non-renewable source	+++
Feed dependency and food security	-
Carbon depletion/soil degradation/fertility decline	+++

- no problem
+ minor problem
++ problem
+++big problem

Here are listed some more specific problems related to the CNP closure in the vegetable agrotypology:

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- the need to improve the soil structure, as vegetable crops often degrade soil structure (due to overuse of soil, multiple agricultural work and passages on fields, lack of organic matter, and large use of chemical fertiliser)
- the need to import carbon and NP as the crop residues are not enough to nourish the soil
- the need to deliver organic material (compost digestate) in a microbiologically safe manner, as some vegetables are consumed fresh.
- the need for a precise distribution of nutrients (in time and space), to control the phases of the phenological cycle of the plant and the qualitative and organoleptic characteristics.
- the need for strict pest control.

N2C solutions tackling the NPC challenges

In Table 24 are reported the solutions applicable to vegetable agrotypology and able to address problems in this sector and are mentioned the two main strategies involved: the increase of nutrient use efficiency (NU) and the import(I) of recovered nutrients from other areas and sectors.

Table 24:Solutions applicable to Vegetable agrotypology and strategies to tackle the CNP challenges

		Strategy	
LL number	Title of the solution	NU	I
LL21	Catch crops and inter-crops	x	x
LL57	Recovered organic materials and composts for precision fertilization	x	X
LL13	Sensor technologies for crops N status	x	
LL47	Utilisation of biochar	x	x
LL10	Anaerobic digestion to increase local nutrient cycling & improve nutrient use efficiency	x	x
LL49	Nitrogen and phosphorus recovery from pig manure via struvite crystallization and design of struvite based tailor-made fertilizers		x

LL21 Using catch crops and inter-crops in rotation.

Catch crops are fast-growing crops put in place during crop rotation**,** while Inter-cropping is a specific cover cropping used in case of large distance sowed crops (growing more than one crop on the same plot with alternating rows).

Both catch crop and intercropping help to increase soil organic matter, reduce soil erosion, enhance nutrient cycling and nutrient use efficiency, water holding capacity, and as a result, potentially increase crop yields, at least in the longer term (Mallast 2014).

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The use of cover crops and intercrops has advantages, but also some disadvantages. One disadvantage is that cover crops can compete with main crops for soil water and nutrients. Wet soil conditions during cover crop destruction can also damage soil structure. Minimum tillage (MT) practices are an important element in the application of cover crops and intercrops (Ghaley 2018). By changing the soil tillage system to a non-ploughing system with shallow cultivation, the chemical properties of the soil may be affected. Still, nutrients and organic matter can accumulate near the soil surface. Although MT has positive environmental effects, productivity remains a major driver for farming, and farmers may not always accept it. However, savings in fuel, labour, and fertiliser costs should be considered for an overall assessment. This group of solutions can catch the remaining nitrogen after harvesting the main crop, so reducing losses from leaching thus improving nutrient use efficiency (NU).

LL57 Recovered organic materials and composts for precision fertilisation

Compost can improve soil structure and fertility, leading to better crop growth and yield. When added to the soil, compost provides a source of organic matter that helps to retain moisture and nutrients, reducing the need for synthetic fertilisers and pesticides. In addition to improving soil health, compost can help reduce soil erosion and water runoff, protecting the surrounding ecosystem. The precision distribution of this material is essential to guarantee the quality of products.

LL 13 Sensor technology to assess crop N status

The N sensor technology measure crop leaves light reflectance (NDVI, normalised difference vegetation index) a proxy of the crops N requirements. However, does not measure the levels of nitrogen in soil.

The utilisation of the N sensor technologies in precision agriculture **(NU) delivers** the correct amount of N in the right place, avoiding overfertilisation (EIP AGRI 2015, 2016). The solutions is able to reduce fertilisers and labour costs, increase crop yields, optimise process inputs, and reduce emissions (air and water). Moreover, Precision Fertilization (PF) made also possible the rapid development of ICT-based sensor technologies and procedures together with dedicated software that in arable farming provides the link between spatially-distributed variables and appropriate farming practices such as tillage, seeding, fertilisation, herbicide and pesticide application, and harvesting.

LL47 Production of growing substrates for horticulture application from poultry manure, solid state digestate and biochar through composting

Biochar is a solid material obtained from the thermochemical conversion of biomass in an oxygen-limited environment. Biochar can be used as a product itself or as an ingredient within a blended product, with a range of applications as an agent for soil improvement and protection against particular environmental pollution and as a possibility for greenhouse gas (GHG) mitigation. Biochar application can replenish key soil nutrients in low fertility soils due to its unique surface charge density, that promotes cation adsorption. Furthermore, biochar can have a variety of physical and structural

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attributes, including but not limited to mechanical strength, porosity, surface area, particle size, and density and structural complexity. In general, in traditional agriculture practice, the application of crop residues in the soil is rapidly degraded by micro-organisms and released as CO_2. Using a thermal conversion of the same residues through pyrolysis, the residues are transformed into a non-degradable carbon. Therefore, the application of biochar into soils is also a suitable technology in carbon capture and storage (CCS). When biochar remains stable in soils makes them more resilient to the effects of climate change, especially the effects of weather extremes. Thus, the solution improves soil quality by introducing long-lasting carbon in the system.

LL10 **Anaerobic digestion to increase local nutrient cycling & improve nutrient use efficiency**

The use of digestate in vegetable agrotypology respond to the strategy of importing (I) recovered CNP from other areas and sector, i.e. digestate provides stabilised organic matter and recovered NP, thus responding to the need for increasing soil organic carbon, provide nutrients and the need to have sanitised material, free from microbiological risks.

Requirements for applicability

The specific requirements for the applicability of each solution at farm level are listed in the tables below.

Table 25: Requirements for implementing solutions in Vegetable Agrotypology

LL21 Catch crops and inter-crops
Requirement 1 to have light soil that allow entering the fields in every season

LL57 composting
Requirement 1 a good quality compost complying regulation

LL13 Sensor technologies for crops N status
Requirement 1 investment cost and a large area to valorise the equipment

LL47 Biochar
Requirement 1 no specific requirement except for the biochar quality

Barriers and possible boosters for implementation

Table 26: Barriers and boosters for solutions in Vegetable Agrotypology

LL	Solution	
	Barriers	Possible booster
21	Pest and disease eventually present	Better management, pest forecast model

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57	Poor quality and lack of quality scheme	Legislation, EU fertilizer quality scheme
13	Investment cost and skills	Aggregation to share investment costs and maximize machine usage
47	Lack of clear quality standard	Quality standard scheme

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8. Orchard agrotypology

Catarina Esteves and David Fangueiro, LEAF, Terra associated laboratory, Instituto Superior de Agronomia, Universidade de Lisboa, Portugal.

Sector outline

Orchards are defined as areas cultivated with specific fruit tree species, and, in this case, we considered apples, pears, peaches, apricots, citrus fruits, olives and vineyards intended to produce table grapes. In 2017[1](Eurostat), the total area occupied by orchards in the EU-28 was almost 6 million ha, which is approximately 8% of the total world production of fruits and citrus trees. Most of EU-28 production is concentrated in the Mediterranean area, where Spain (50%) and Italy (23%) are the biggest contributors, followed by Greece (13%) and Portugal (5%) (Figure 1). In terms of land use, permanent crops occupy 6% of EU agricultural land.

In EU-28, apple trees (8%), orange trees (4%) and peach and nectarine trees (3%) occupied the largest areas (data from 2017). Poland is the biggest apple producer, followed by Italy and Romania, and Spain, Italy and Greece are the biggest producers of oranges, peaches and nectarines.

Vineyards occupied an area of more than 3 million ha in 2020 (EU-27)

In terms of organic production, permanent organic crops, such as the fruit orchards and vineyards mentioned, represent 12% of the total organic area in the EU (total organic area in the EU accounts for 14.7 million ha in 2020, which is 9.1% of agricultural land in the EU). This 12% is much less than the 46% and 42% representing organic arable land and organic pastures, respectively. Organic permanent crops account for the lowest share of these three types of crops, as alternative organic fertilisers have been scarcely used in permanent crops (Chatzistathis et al., 2021). Notwithstanding, Cyprus and Malta have the highest share of permanent organic crops in the EU, with 47.6% and 38.8% of their total organic area, respectively.

Seeing the relevance of fruit production in Europe and the little significance of organic farming in this sector, there is a great opportunity for manure application in orchards, as also stated by Fangueiro et al. (2021).

In terms of fertiliser use, it has been decreasing in the last few years, since the 90s, across all sectors. This trend will continue and a decrease of 4.6% is foreseen between 2021 and 2031 in the use of synthetic fertilisers (N+P+K) (Eurostat, Fertiliser Europe) due to tightening of the environmentally

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friendly EU policies. If chemical fertilisers are replaced in permanent crops, there is potential to reduce the consumption of fertilisers by 6% in the EU (Figure 2).

Table 27: Orchard Agrotypology factsheet

Parameter	Unit	Value
Orchard area (EU-28) - 2017	ha	5 947 860.54
Permanent* crops output (EU-27) - 2021	million €	4 878.85
N removed by harvest of fruits (EU-27) - 2014	T	423 157
P removed by harvest of fruits (EU-27) - 2014	T	159 929

* including apple fruits, citrus fruits, grapes, wine and olive oil. Data from Eurostat https://ec.europa.eu/eurostat/.

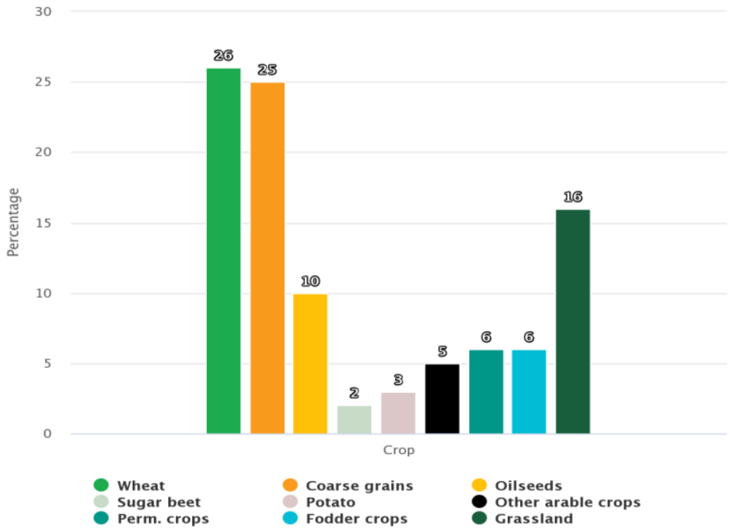

Figure 12: Fertiliser consumption by crop in EU (Note: due to rounding, figures may not add up to 100%) Fertilizers Europe.

Problems and challenges of the sector related to the CNP closure

In Figure 13 is reported the share of UAA dedicated to permanent crops (e.g., orchard) at NUTS2 level, and the N and P surplus in the land dedicated to this sector. In the elaboration of the map has to be noted that the N and P application is based on the crop yield. Perennial crops have relatively low crop yields and therefore the calculated N surpluses can, especially in the Mediterranean region, be underestimated. Nitrogen and phosphorus surplus are detected in areas contiguous to livestock farming more than in areas with a high vocation for perennial crops (compare first map of Figure 13 with second and third) while a negative carbon balance is visible for this agrotypology (Figure 14)

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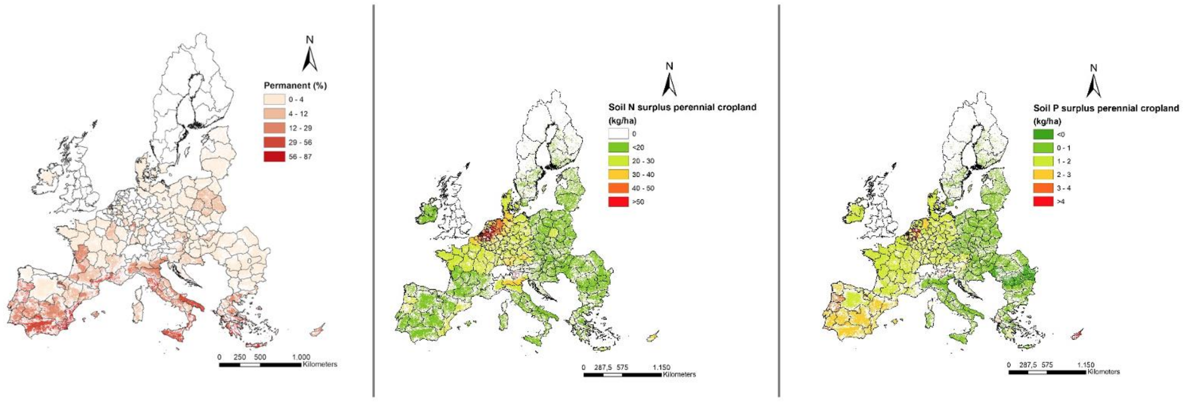

Figure 13: share of UAA dedicated to permanent cropland at NUTS 2 level, and the soil N and P surplus of perennial cropland.

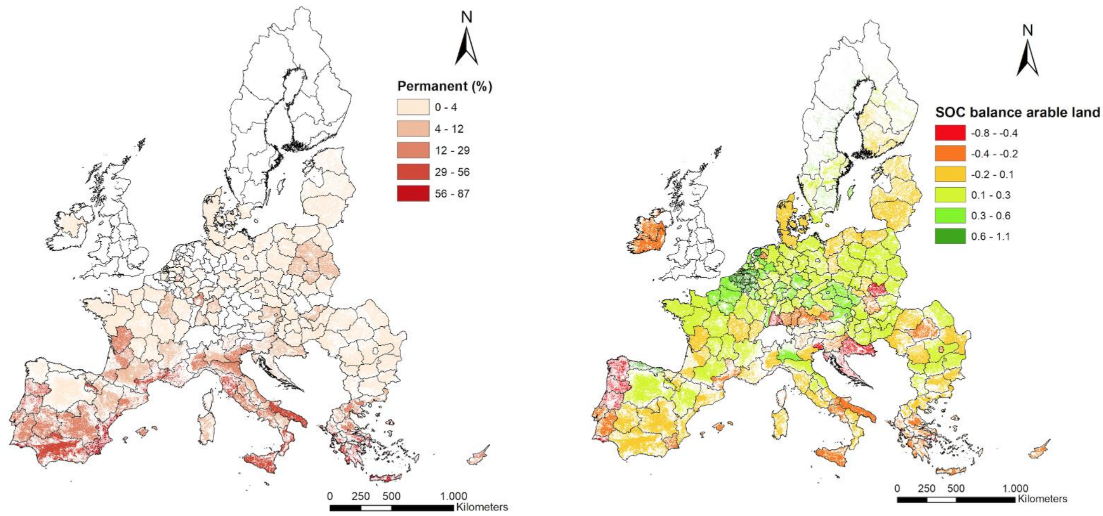

Figure 14: share of UAA dedicated to permanent cropland at NUTS2 level, and the SOC balance of arable land (NUTS 2 level). These maps are based on the results of the MITERRA-Europe Model (Velthof et al.,2009).

A general overview of problems of orchard farming systems related to NPC cycles are reported in the table below, with a qualitative estimation of the extent.

Figure 15: Extent of the problems related to CNP cycles in Orchard Agroptyology

Problem	Extent of the problem
N surplus	-
P surplus	-
NH_3 emissions	+
N leaching	+++
GHG	+

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NPC dependency from a non-renewable source	+++
Feed dependency and food security	-
Carbon depletion/ soil degradation/ fertility decline	+++

- no problem
+ minor problem
++ problem
+++big problem

Orchards and vineyards are great C sinks due to their long-life cycle which enables them to store C in the trunks, branches and roots. Also, most have low or no tillage and have natural or planted herbaceous vegetation in the interrow, which contributes to the preservation and build-up of organic matter in the soil (Scandellari et al., 2016). As such, orchards and vineyards are more efficient in storing and sequester C than other crops, which minimises their impacts on the environment (Sugiura et al., 2017). However, carbon depletion in soil is still a challenge for this agrotypology, moreover orchards are mostly present in the southern countries of the EU (except for some eastern countries, such as Poland which is the main EU apple producer), and these regions are characteristic of alternated periods of drought and heavy rainfalls. This characteristic leaves the soil more susceptible to erosion and degradation (Walmsley and Cerdà, 2017). The use of heavy machinery, pesticides and herbicides that are employed in intensive farms also negatively impacts soil health and the environment.

The use of mineral fertilisers does not maintain or improve soil fertility in the long term, as crops remove organic carbon from the field each growing season after harvesting. If not supplemented with organic matter, soil fertility will decrease (Chatzistathis et al., 2021). This decline in soil fertility and health may be halted by the use of organic manures and slurries (Fangueiro, 2021).

Looking at NP fertilisation, permanent crops have complex growth cycles and variable nutrient demands. So, planning the N fertilisation rate and timing may be difficult and can lead to improper and excessive use of synthetic N fertilisers, with potential impacts on soil and water quality. On the bright side, permanent crops have higher root density and overall size compared to other crops, which can more easily capture nitrate and prevent it from being lost to the deeper soil layers (Cui et al., 2020).

Specific problems and challenges of the sector are:

Nutrient overapplication: Due to the intensification of production in orchards, and the difficulties of planning fertilisers application, there has been an improper and excessive use of N fertilisers, which has caused nitrate leaching in some regions (Cui et al., 2020). N and P are historically used in excess in orchards, with applications estimated to be almost three times higher than the plant requirement (Lu et al., 2015). Improper fertilisation, either in terms of rate or timing, causes low use efficiency of fertilisers. Application of fertilisers disregarding spatial intra-variability of orchards also decreases the use efficiency of these inputs, since some areas receive nutrients in excess and others are in deficit. For instance, Aggelopoulou et al. (2011) found that if N-fertilisers are applied considering spatial variability within the orchard, 38% of N could be saved compared to the uniform rate.

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Nutrient loss: due to improper fertilisation plans and excessive irrigation, nutrients are expected to be washed away into deeper soil areas and groundwaters. A meta-analysis of orchard fertilisation revealed that 18.5% of N input is lost as nitrate, and total losses represent 26.3% of N input (Zhao et al., 2022). Due to C sequestration in this sector, C balance is usually positive in contrast to annual crops

Organic matter depletion a soil degradation: the excessive use of agricultural inputs due to the intensification of farming systems has led to soil depletion and soil erosion with strong impacts on soil microbial biomass (Chatzistathis et al., 2021). By reducing soil microbial activity, the recycling and renovation of soil nutrients will be affected and, in turn, harm nutrients' bioavailability.

N2C solutions tackling the CNP challenges

Three solutions were identified in the N2C project able to tackle the main challenges of the sector, according to two main strategies:

- Improve the efficiency of nutrient use **(NU),**
- Import of recovered CNP from other areas or sectors **(I)**

Table 28: Solutions applicable to Orchard Agrotypology and strategies to tackle the CNP challenges

LL number	Title of the solution	Strategy	
		NU	I
15	Substituting mineral inputs with organic inputs in organic viticulture		x
57	Recovered organic materials and composts for precision fertilisation of apple orchards and vineyards	x	x
66	Application of digestate in large scale orchards		x

LL 15 is a farm-specific solution to organic arable crops and vineyards and has a regional dimension. It uses bio-based fertilisers (BBF), which comply with the criteria defined for organic farming, to fertilise the crops and to increase soil fertility levels and C storage. It promotes nutrient circularity by recovering oil cakes from the production of seed oil, which is then used as livestock feed or as BBF. In this solution, the crop residues are also used as BBF, further promoting nutrient circularity within vineyard production. Another relevant aspect of this solution is the communication with regional authorities to facilitate the use of Precision Agriculture (PA) tools in smaller farms, thus making this solution available for all farm sizes.

LL 57 uses PA techniques and other tools to optimise the efficiency of animal manures and slurries as substitutes for mineral fertilisers. The perennial crops are themselves great C sinks and storages. Still, the use of animal manures helps restore soil's microbial communities and activity, promoting nutrient cycling in the soil and increasing the nutrients' bioavailability. The use of these organic materials is essential in southern EU countries that have characteristically low levels of soil organic matter content

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and, consequently, low fertility. Through the use of PA techniques, soil's intra-variability is considered and accounted for when adjusting the fertiliser input in crop production. As such, the application rate is adjusted to the soil's fertility level and crop health status so that areas within the vineyard or orchard that have low fertility or have lower productivity receive higher amounts of input and areas with high fertility or higher productivity might receive less. Thus, crop productivity is more homogeneous within the field, which leads to higher yields, higher input efficiency, and fewer nutrient losses.

The LL 66 also consists of using BBF as a partial replacement for mineral fertilisers in a raspberry orchard. The BBF is a digestate produced from a biogas installation, which happens to be in the proximity of the orchard in the study, further promoting N, P and C cycling at the regional level. Similarly to LL57, by replacing mineral fertilisers with these organic materials, the solution simultaneously and consequently reduces the EU's dependence on the importation of mineral nutrients, it reduces the farmer's costs per unit of yield (since the fertiliser prices are extremely high) and the associated environmental impacts of mining for mineral nutrients are also reduced. The digestate is a nutrient-rich material, more stable than animal manure since it is subjected to anaerobic digestion that also eliminates weed seeds and harmful bacteria (such as *Salmonella spp. or E. coli*). Besides producing digestate and other nutrient-rich by-products, the biogas produced during anaerobic digestion can be used as green energy, which is very important in today's context of high gas prices and the EU's dependence on gas importation. This further extends the benefits of using digestate, in contrast to mineral fertilisers.

LL15 is a more local, on-farm solution and **LL66 is** more directed to the entire region. Regardless, in either of the three solutions tackled in this agrotypology, nutrients are recovered from animal manures and slurries or from the by-products of agricultural production, with the purpose of reducing the use of mineral fertilisers and reducing all of the associated costs, both financial and environmental costs.

Requirements for applicability

The specific requirements for the applicability of each solution at the farm level are listed below.

Table 29: requirement for implementing solutions in Orchard Agrotypology

Solution
LL 15
Requirement 1 Quality equipment for pressing oil seeds to get a homogeneous oil cake for each pressing session
Requirement 2 -Analysis of oil cake to get accurate data about nutrients content
LL 57
Requirement 1 Farm size, in both land and economic size, to implement Precision Agriculture techniques and technologies

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Requirement 2 Technical knowledge to obtain and interpret data from the PA technologies and advise the farmers
Requirement 3 Specific machinery that enables variable-rate application of BBF
LL 66
Requirement 1 Minimum of one hectare of orchard area
Requirement 2 The proximity of the biogas plant due to the easier transport of digestate
Requirement 3 Preliminary and regular soil analysis to optimise fertilisation rates
Requirement 4 Technologist experienced in (in)organic fertilisers management to meet crops needs and adjust fertilisation rates to the good agricultural practices

Some requirements are common to all solutions, such as machinery and labour for the application of the BBF to the soil. LL57, however, does require specific machinery that enables variable-rate application of BBF and LL15 requires machinery for the incorporation of crop residues in the soil. It should be given priority to the BBFs obtained in the proximity of the farms, to maximise nutrient cycling at the regional level but also to decrease the cost of these materials, as the transport costs are a significant part of the production costs.

Obviously, for all solutions, it is also imperative to have the farmer's acceptance of using these products, which have some limitations compared to the use of mineral fertilisers. So, an adequate characterisation of the BBF and a deep understanding of the nutrient dynamics after their application to the soil are of the utmost importance. This knowledge allows the matching of the nutrients released from the BBFs, in terms of quantity and timing, with the crop's demands and maximises the use efficiency of these organic materials. Consequently, it also increases farmers' acceptance.

LL15 requires the matching of the BBFs with the organic farming standards, in terms of nutrient efficiency and pricing. It also requires collaboration with local governmental institutions to enable the use of Precision Agriculture tools. Solution LL57, which also uses components from PA, has a similar requirement, as the implementation of PA is complex and often expensive, thus it is only encouraged when the profits surpass the costs. Similarly to LL15, farmers' collaboration with governmental authorities or associations may lessen these costs and increase the adoption of this practice.

Barriers and possible boosters for implementation

In table below are reported barriers and possible boosters to a wider implementation of the identified solutions for orchard agrotypology

Table 30: Barriers and boosters for solutions in Orchard Agrotypology

Solution	Barriers	Possible boosters
LL15	Storage conditions at farm to keep product (oil cakes) stability	Increasing prices of fertilisers;

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LL57	Costs of technologies and specific machinery. Higher greenhouse gas emissions (GHG) with liquid slurries. Variable and long mineralization rates of manures	Collaboration with farmer's associations or government authorities to lessen the cost of PA implementation. national or EU packages promoting the adoption of these measures; slurry treatments; more studies to understand nutrient dynamics following manure application
LL66	Not possible to subsequently add more digestate (permanent plantation, raspberries are in raised beds)	

One of the major barriers to using animal manures and slurries as fertilisers is that the nutrient content, in terms of N, P and K, does not match the crop's needs. In contrast, it is possible to make the optimal formulation of NPK with mineral fertilisers. A Nutri2Cycle study has shown that that is also possible with animal manures and slurries, by blending and matching different effluents to obtain a specific NPK ratio (see SRL5-LL62).

Another difficulty is estimating their mineralisation rate, i.e., the rate at which the organic nutrients are transformed into mineral nutrients by the soil's microbial communities, which is long and dependent on various factors, such as manure composition, duration of storage, soil characteristics, and weather. Having a deep understanding of the nutrient dynamics during manure mineralisation in the soil is crucial for adequate crop fertilisation, so that the timing of nutrient release from the manure, into a plant-available form, matches the time when crops have high nutrient demands. More studies are still needed to better estimate the mineralisation rates of these organic materials; however, some indicative N mineralisation rates are available for specific EU regions which might help farmers better adapt the application rate of MBFs. For instance, in Portugal, it is estimated that in the first year after its application, 60% of the total N in cattle slurry is mineralised and made available for plants (Order N.º 1230/2018 of Portuguese Ministry for Agriculture[2]). The timing and rate of application of these materials can then be based on this knowledge.

The use of mineral fertilisers is deeply rooted within the farmer's practices and the use of animal manure might not always achieve the productivity obtained with mineral fertilisers. However, more and more studies are presenting the benefits of using these materials in soil fertility and crop productivity. Showcasing these scientific results and communicating with farmers is also a very important step for the implementation of these measures.

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EuroStat

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https://ec.europa.eu/eurostat/databrowser/explore/all/agric?lang=en&subtheme=agr.orch_vit&display=list&sort=category (accessed online on 15th January 2003)

Fertilizers Europe

https://www.fertilizerseurope.com/ (accessed online on 25th January 2023)

Data from EuroStat https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Organic_farming_statistics#Total_organic_area

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9. Organic agroforestry

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Sector outline

Agroforestry is a particular type of land-use system and technology where woody perennials (trees, shrubs, etc.) are used on the same land management unit as agricultural crops and/or animals. In general agroforestry is a form of multiple cropping which satisfies at least three basic conditions:

1. There are at least two species that interact biologically.

2. At least one of the species is a woody perennial.

3. At least one of the plant species is managed for forage, annual or perennial crop production (EC 2022).

In Europe the total area under agroforestry in the EU-27 is about 15.4 million ha which is equivalent to about 3.6% of the territorial area or 8.8% of the utilised agricultural area (UAA) with a high heterogeneity between member states. Spain (5.5 million ha), Greece (1.6 million ha), France (1.6 million ha), Italy (1.4 million ha), Portugal (1.2 million ha) and Romania (0.9 million ha) have the largest absolute extent of agroforestry (Figure 16). However, if we look at the extent of agroforestry in relation to the UAA, countries like Cyprus (40% of UAA), Portugal (32% of UAA) and Greece (31% of UAA) have the largest percentage of agroforestry cover (see table X2).

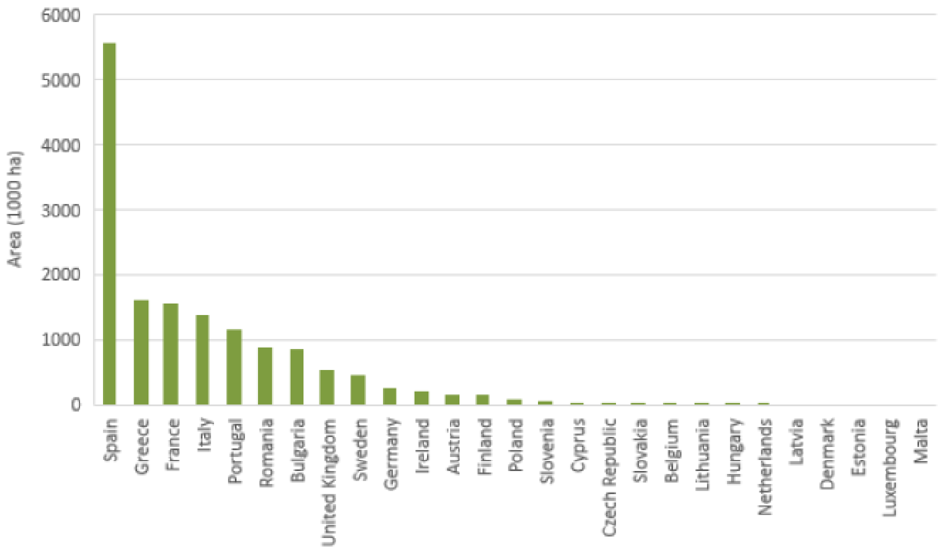

Figure 16. Extent of area covered by agroforestry in the EU-27 Source: Den Herder et al. 2016

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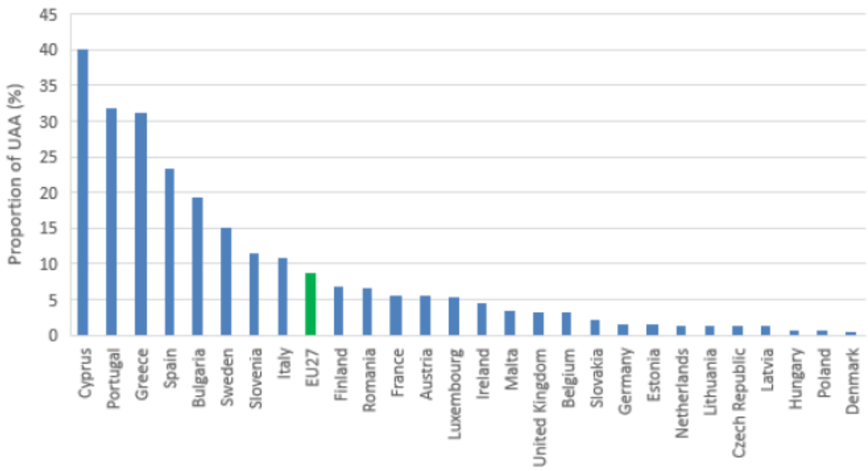

Figure 17: Extent of agroforestry as a proportion of the Utilised Agricultural Area in the EU27. Source: Den Herder et al. 2016

In the EU there are many types of agroforestry which are difficult to classify due to the high number of possible combinations of woody components/crops/livestock and the variety of criteria to consider. In the literature exists a range of methods for categorising agroforestry practices. McAdam et al. (2009) based the categorisation of practices in agroforestry on components, products, agro-ecological zones and socio-economic grouping. Based on classification in America Mosquera-Losada et al. (2009) classified European agroforestry into six agroforestry practices: silvoarable agroforestry, forest farming, riparian buffer strips, improved fallow, multipurpose trees and silvopasture. In addition, novel silvoarable and silvopastoral systems such as alley cropping, woodland chicken breeding, and food forestry such as fruit trees are relevant in the EU (Den Herder et al. 2016).

In this chapter we follow a more recent categorisation of Den Herder et al. 2016 developed within the AGFORWARD research project funded within the 7th Framework Programme of RTD aimed at better understanding the context and extent of agroforestry in Europe. Following this approach the European agroforestry can be classified into:

1. High value tree agroforestry
   - Intercropped and grazed fruit, olive and nut tree area
2. Arable agroforestry
   - Silvoarable, silvopastoral agroforestry e.g. in combination with permanent crops (planted fruit, nut and olive trees) and woodlands
3. Livestock agroforestry
   - Combined with permanent crops, woodland, shrublands with sparse tree cover and grassland with sparse tree cover

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Spain (261 thousand ha), Italy (202 thousand ha), Portugal (154 thousand ha) and Greece (137 thousand ha) have the largest absolute extent of high value tree agroforestry (see Table 31). The largest extent of intercropped high value trees is found in Italy (90 thousand ha) followed by Spain (52 thousand ha) and Portugal (36 thousand ha). The largest extent of grazed high value tree practices is found in Spain (217 thousand ha), Greece (123 thousand ha), Portugal (123 thousand ha) and Italy (116 thousand ha) (Den Herder et al. 2016).

The largest extent of arable agroforestry can be found in Spain (5.4 million ha), Greece (1.6 million ha) and France (1.5 million ha). Silvoarable agroforestry can be found mainly in Spain (117 thousand ha) and Italy (106 thousand ha). The largest area of arable agroforestry with permanent crops (planted fruit, nut and olive trees) is found in Italy (90 thousand ha) followed by Spain (52 thousand ha) and Portugal (36 thousand ha). The largest extent of arable agroforestry in woodlands is found in Spain (65 thousand ha) and Portugal (40 thousand ha) where the mainly oak-dominated woodlands often combine silvopastoral and silvoarable practices.

The largest extent of livestock agroforestry systems can be found in the Mediterranean countries: Spain (5.5 million ha), Greece (1.6 million ha), France (1.6 million ha), Italy (1.3 million ha) and Portugal (1.1 million ha). Livestock systems associated with permanent crops are found mainly in Spain (217 thousand ha), Greece (123 thousand ha) and Portugal (122 thousand ha). The largest areas of livestock systems on woodland are in Spain (3.5 million ha), Portugal (799 thousand ha), Greece (656 thousand ha), France (648 thousand ha) and Italy (622 thousand ha). Livestock agroforestry on shrublands with sparse tree cover is found predominantly in Spain (589 thousand ha) and Greece (534 thousand ha). The largest extent of livestock agroforestry on grassland with sparse tree cover is found in Spain (1.2 million ha), France (749 thousand ha) and Romania (670 thousand ha).

Table 31: Total extent of agroforestry in Europe based on LUCAS data (Den Herder et al. 2016)

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Country	Total territorial area	Utilised Agricultural area (UAA)[1]	High value tree agroforestry	Livestock agroforestry	Arable agroforestry	All agroforestry	Estimated proportion of total territorial area	Estimated proportion of UAA
	1000 ha	1000 ha	1000 ha	1000 ha	1000 ha	1000 ha	%	%
Austria	8388	2878	23.3	158.2	1.3	160.8	1.9	5.6
Belgium	3053	1358	2.5	43.7	0.0	43.7	1.4	3.2
Bulgaria	11090	4476	26.7	866.5	3.3	869.9	7.8	19.4
Cyprus	925	118	10.3	43.6	3.8	47.5	5.1	40.1
Czech Republic	7887	3484	7.2	45.8	0.0	45.8	0.6	1.3
Denmark	4290	2647	0.0	14.9	1.2	16.2	0.4	0.6
Estonia	4523	941	0.0	14.4	0.0	14.4	0.3	1.5
Finland	33843	2291	0.0	158.1	0.0	158.1	0.5	6.9
France	54397	27837	58.2	1557.9	5.7	1562.2	2.9	5.6
Germany	35713	16704	35.8	257.7	5.7	263.5	0.7	1.6
Greece	13196	5178	136.5	1601.2	15.2	1616.4	12.2	31.2
Hungary	9302	4686	2.0	36.1	2.0	38.1	0.4	0.8
Ireland	6980	4991	0.0	224.4	0.0	224.4	3.2	4.5
Italy	30134	12856	202.2	1303.6	106.1	1403.9	4.7	10.9
Latvia	6456	1796	0.0	23.4	0.0	23.4	0.4	1.3
Lithuania	6530	2743	8.4	36.9	1.7	38.6	0.6	1.4
Luxembourg	259	131	2.4	7.2	0.0	7.2	2.8	5.5
Malta	32	11	0.0	0.4	0.0	0.4	1.3	3.5
Netherlands	4154	1872	3.7	27.8	0.0	27.8	0.7	1.5
Poland	31268	14447	14.3	97.5	2.9	100.4	0.3	0.7
Portugal	8909	3668	154.2	1105.1	76.5	1168.3	13.1	31.8
Romania	23839	13306	80.1	878.2	10.0	888.2	3.7	6.7
Slovakia	4904	1896	2.0	41.9	2.0	43.9	0.9	2.3
Slovenia	2027	483	3.8	56.3	0.0	56.3	2.8	11.7
Spain	49851	23753	260.7	5490.0	117.0	5584.4	11.2	23.5
Sweden	43858	3066	2.0	463.6	2.0	465.5	1.1	15.2
United Kingdom	24853	16882	14.2	547.6	2.0	551.7	2.2	3.3
EU-27 total	**430659**	**174499**	**1050**	**15102**	**358**	**15421**	**3.6**	**8.8**

Key challenges in closing CNP loops in agroforestry

Agroforestry has been increasingly recognised as a promising pathway aiming at sustainable agriculture with regard to healthier soils for increased agricultural production and environmental performance (Snapp et al., 2010; Pretty, 2018). Besides provisioning food, fodder, fibre and fuelwood production, agroforestry provides several other ecosystem services, including regulation of nutrient cycling, carbon sequestration, habitat for biodiversity, erosion control, fire and flood control and recreational and cultural services (Norrlin et al 2020).

Major challenges for the lack of implementation of agroforestry are:

(1) uncertainties for the farmers on how to best establish and manage agroforestry practices,

(2) economic issues related to the development of business plans,

(3) adequate development of the value chains of the multiple agroforestry products and consumers awareness and

(4) lack of adequate policies aimed at supporting agroforestry systems (Mosquera-Losada et al., 2018, Santiago-Freijanes et al., 2018).

Respect to CNP closure agroforestry presents two main advantages, respect to conventional farming, i.e. higher nutrient use efficiency and reduced nutrient loss, together with high carbon sequestration.

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Nutrient use efficiency: Given their structural and functional complexity, agroforestry systems demonstrate complex nutrient dynamics, especially compared to conventional agriculture systems. In agroforestry systems, internal N cycle through direct transfer of fixed N from tree to crop, N2 fixation through leguminous trees, N mineralisation of organic matter from tree litter, pumping of subsoil N by tree roots and ammonia captured by trees are far larger than conventional external N input from organic amendment and inorganic N fertiliser (Kim and Isaac, 2022).

In conventional agricultural systems, only a share of the applied N and phosphorous fertiliser is taken up by crops. Agroforestry systems such as riparian buffers help clean runoff water by reducing the velocity of runoff, thereby promoting infiltration, sediment deposition, and nutrient retention. Buffers also reduce nutrient movement into ground water by taking up the excess nutrients (Jose, 2009). Trees with deep rooting systems in agroforestry systems improve groundwater quality by serving as a "safety net" whereby excess nutrients that have been leached below the rooting zone of agronomic crops are taken up by tree roots. These nutrients are then recycled back into the system increasing the nutrient use efficiency of the system (Allen et al., 2004).

A meta-analysis of Kim and Isaac (2022) showed that the nutrient use efficiency is generally higher compared to conventional agriculture due to higher N outputs through enhanced crop yields and timber production, and lower N losses through reduced soil erosion, runoff and gaseous N emissions.

Nitrogen losses: Several studies showed the positive impact of agroforestry on N loss. A meta-analysis of global studies on silvoarable agroforestry, silvopastoral systems, linear tree plantings and riparian and upland buffers by Zhu et al. (2020) found that agroforestry reduced N loss (caused by leaching, runoff and soil losses) by 55–60 %. Similar results have been found for the effects of agroforestry on nitrate leaching reducing nutrient losses by 40–70% because tree roots are deeper and can use leached nutrients that crop roots cannot reach which are then recycled into the system through leaf litter and turnover of fine roots (Nair et al. 2007; Jose 2009). Nutrient availability and cycling have been shown to be greater and more efficient in agroforestry, compared to conventional agro-ecosystems via the incorporation of nitrogen-fixing tree species or the use of leguminous crops in crop rotation or as cover crops lead to increased stocks of nitrogen (Sollen-Norrlin et al., 2020). In agroforestry biomass production of the trees is faster than in forests as there is less competition amongst the trees and the rapidly produced biomass can then be recycled back into the system, which improves soil organic matter (SOM) content and nutrient recycling. In agroforestry systems the recirculation of N, reduced N loss and N sequestration also decrease the demand for new N and the dependence of farmers on external N input (Kim and Isaac 2022). As a co-benefit, this recirculated and sequestered N in both soil and plant biomass can also play a key role in soil carbon sequestration (Du et al. 2020) and in the abatement of gaseous N losses (Kim et al. 2016). While agroforestry systems reduce N loss via soil erosion, runoff and leaching, gaseous N loss including NO and N_2O emissions also occurs in these systems.

Carbon sequestration: One of the main environmental benefits of agroforestry systems is the increased carbon sequestration as a large portion of organic C returns to the soil in the form of crop

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residues and tree litter helping to stabilise SOM and decrease biomass decomposition rate. Literature showed that for the EU the carbon sequestration is increased by agroforestry compared to conventional farming systems potentially contributing to climate change mitigation. A meta-analysis for agroforestry in the EU indicates significant decrease in soil organic carbon (SOC) stocks, between 24 and 26%, in the land-use change from forest to agroforestry. The transition from agriculture to agroforestry significantly increased SOC stocks, between 26% and 34%, and conversion from pasture/grassland to agroforestry produced significant SOC stock increases ranging between 9 and 10% (De Stefano and Jacobson, 2018).

Despite the benefits, this agrotypology also needs to close the nutrient cycle, **in particular to import nutrients to support production** respect to a basal level that might not be economically sustainable. The general problems of agroforestry systems related to NPC cycles are summarised in the table below, with a qualitative estimation of the extent.

Table 32: Extent of the problems related to CNP cycles in Agroforestry Agrotypology

Problem	Extent of the problem
N surplus	-
P surplus	-
NH_3 emissions	-
N leaching	-
GHG	-
NP dependency from non-renewable source	+
Feed dependency and food security	+
Carbon depletion/soil degradation/ fertility decline	-

- no problem
+ minor problem
++ problem
+++big problem

N2C solutions tackling the CNP challenges

The N2C solution able to tackle the main challenges of the sector can act according to these main strategies such as depicted in WP2, D.2.1.

- Increased efficiency of nutrient use
- Import recovered CNP from other areas or sectors

In the case of the N2C agroforestry solution followed in France, we became interested in the situation of the Manicot farm, a mixed crop-livestock farm with 93 ha of agricultural area, LL14.

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The strategy of the solution is to increase the import and of nutrients (I), including carbon, nitrogen and phosphorus, to be valorised in the agroforestry plot, distributed according to precision approach, thus improving the nutrient use efficiency (NU).

Table 33: solution for Agroforestry Agrotypology

		Strategy	
Solution	**Title of solution**	**Increased efficiency of nutrient use (NU)**	**Import recovered CNP from other areas or sector (I)**
LL14	Closing the loops at the scale of farm: using the livestock manure to fertilize the feeding crop on agroforestry plots	x	x

This farm combines arable crops, such as wheat, triticale, pea, corn, and rapeseed and goose breeding.

On this farm, one arable plot has been planted with agroforestry for energy wood production. Before the N2C project, the crops of this plot were only fertilized with synthetic or mineral products, while the solution foresees the input of goose manure and slurry, with substitution of synthetic fertilising products with local organic ones.

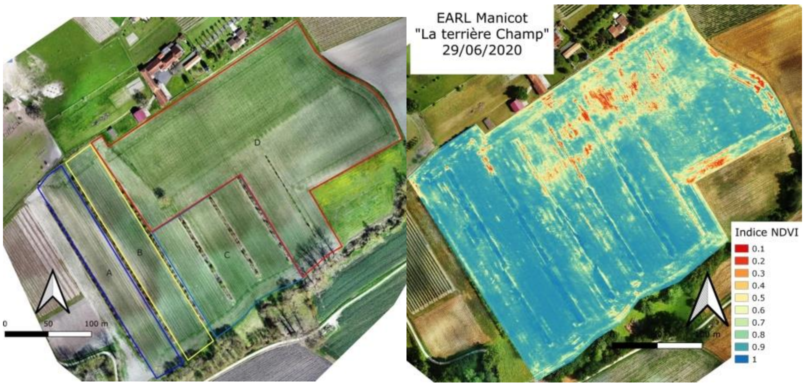

Figure 18. map of agroforestry trials

The solution is able to increase the N content available and thus allow a better development of the crop (ndvi map made from remote sensing data in the figure below).

Requirements

The specific requirements for the applicability of the solution at farm level are listed in the table below

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Table 34: requirements for solution in Agroforestry Agrotypology

Solution LL14: Livestock manure to fertilize the feeding crop on agroforestry plots
Requirement 1 A fertilizing program for each crop on the plot with the analysed data of the effluents to spread
Requirement 2 A good relationship with neighbourhood to make spreading operations more acceptable
Requirement 3 To participate in experimentation programs to obtain references about the best spreading practices

Barriers and possible booster

Table 35: barriers and booster for solution in Agroforestry Agrotypology

Solution LL14 Livestock manure to fertilize the feeding crop on agroforestry plots	
Barriers	**Possible booster**
Storage issues	A label about sustainable energy or good carbon footprint on the farm products to identify the farm action
Effluent poor contents in nutriments	Financial help to set up a treatment device for effluent.
French application of Nitrate Directive	Legislative update
Neighbourhood hostility	Information and dissemination activities

Reference Agroforestry Agrotypology

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Nutri2Cycle
Nurturing the Circular Economy

10. Manure processing Agrotypology

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Sector outline

Manure processing is an important activity with a direct link to animal husbandry. In order to achieve the European targets for reducing the loss of nutrients to the environment and the reduction of greenhouse gases, manure processing enjoys considerable attention in the EU. In total 7.8% of the livestock manure production in the EU, equal to 108 million tons, containing 556,000 ton of nitrogen and 139,000 ton of phosphorus is being processed (Foged, 2011). In the beginning of the past decade, there were 17894 farm size manure processing installations, 943 small/medium size installations (< 50,000 tonnes/year), and 359 large scale installations (>50,000 tonnes/year).

Manure processing encompasses tens of manure processing technologies, which are being divided in six main categories:

- **Separation** (mechanical or chemical): it has the objective of separating manure into two flows: a concentrate (solid fraction) and a diluted fraction (liquid fraction). Examples of separation are screw pressing, centrifugation, air flotation, …
- **Additives and other pre-treatments:** it has the objective to prepare the material for further purpose or treatment. Examples are (bio)acidification, temperature and pressure treatment, manure additives, …
- **Anaerobic digestion**: it is a series of biological processes in which microorganisms break down organic molecules in absence of oxygen, resulting in the production of biogas and digestate. The biogas can be used as a renewable energy source, while the digestate could be a valuable fertiliser because of the increase in N plant availability.
- **Treatment of the solid fraction**: the solid fraction contains most of the C and P with a DM content around 25%. There exist several technologies to further process the solid fraction, such as composting, thermal drying, pelletising, incineration, …
- **Treatment of the liquid fraction**: the liquid fraction contains most of the N and K with a DM content around 2%. There exist several technologies to further process the liquid fraction, such as reverse osmosis, stripping-scrubbing, nitrification-denitrification, constructed wetlands, …
- **Air cleaning**: in pig husbandry and during some manure treatment technologies (e.g. composting), it is obligatory to clean process air in order to limit (ammonia) emissions. Examples are air scrubbing (acidic or biological) or biofiltration.

Manure processing is mainly important in livestock intensive areas (such as Flanders, the Netherlands, Denmark, Brittany, …), where the Nitrates Directives limit the amount of animal manure that can be applied to the field to 170 kg N/ha. Excess of manure needs to be processed in order not to harm the environment or exported to "nutrient-poor" regions.

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Efficient nutrient recycling during manure processing is implemented by following prerequisites [1]:

- Maximising biogas yield is the most important factor for viable installations.
- Nutrients in co-substrates, probably needed to boost biogas production should be included in the nutrient balance.
- Spreading of manure should always occur preferably in spring and early summer to maximise nutrient uptake of growing plants.
- As the nitrogen components in digestate leach more easily than in raw manure, time for spreading is even more important.

Oenema et al. (2007) indicate that maximally 52% of the N excreted in barns is effectively recycled as plant nutrient (Oenema 2007). However, a lot of potential remains nowadays to recycle nutrients efficiently during manure processing. Köninger et al. (2021) found that coupling manure management with soil biodiversity can mitigate present and future environmental risks. Analyses showed that manure quality is more important to soil biodiversity than manure quantity and therefore, agricultural practices that protect and promote soil biodiversity with the application of appropriate, high-quality manure or biostimulant preparations based on manure, could accelerate the move towards more sustainable food production systems. Soil biodiversity needs to be appropriately factored in when assessing manure amendments to provide better guidelines on the use of manure and to reduce costs and environmental risks. However, radical changes in current philosophies and practices are needed so that soil biodiversity can be enhanced by manure management.

Table 36: Manure Processing factsheet

Parameter	Unit	Value
Number of companies in EU	n	+-19000
Share of manure that is processed in EU	%	7.8

Problems and challenges of the sector related to the NPC closure

Manure processing is an important tool in helping to solve the challenges **arising from livestock agrotypologies, i.e. and manure production and concentration,** thus relates with the problems and challenges presented in Chapter 1 (pig agrotypology), chapter2 (cattle agrotypology) and chapter 3 (poultry agrotypology).

According to the European Green Deal, nutrient losses need to be reduced by 50% by 2030. Manure processing is an important aspect of this target and is getting more and more important. At the same time, the Circular Economy Action Plan paves the way for a cleaner and more competitive Europe, including an Integrated Nutrient Management Plan, with a view to ensure more sustainable application of nutrients and stimulate the markets for recovered nutrients (Koninger et al 2011).

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The manure processing industry needs to make the **switch from removing nutrients to recovering nutrients**. A lot of interesting technologies already exist, but often full market uptake is hindered by legislative aspects. For example: end products are often still considered as animal manure, which has the consequence that they need to comply with the Nitrates Directive. Ammonium sulphate from air scrubbing is one product that can already be applied on top of the Nitrates Directive. It is expected that the sales market of other manure derived products (e.g. RENURE products) will strongly increase when these products would have the same legal status as mineral fertilisers.

In 2020, manure management was responsible for the emission of 56,716 k ton CO_2 equivalents in Europe (Eurostat, 2022), mainly due to CH_4 emissions from manure management, which is the **third most important source of agricultural emissions**, accounting for about 10% of the total emissions (EEA 2022).

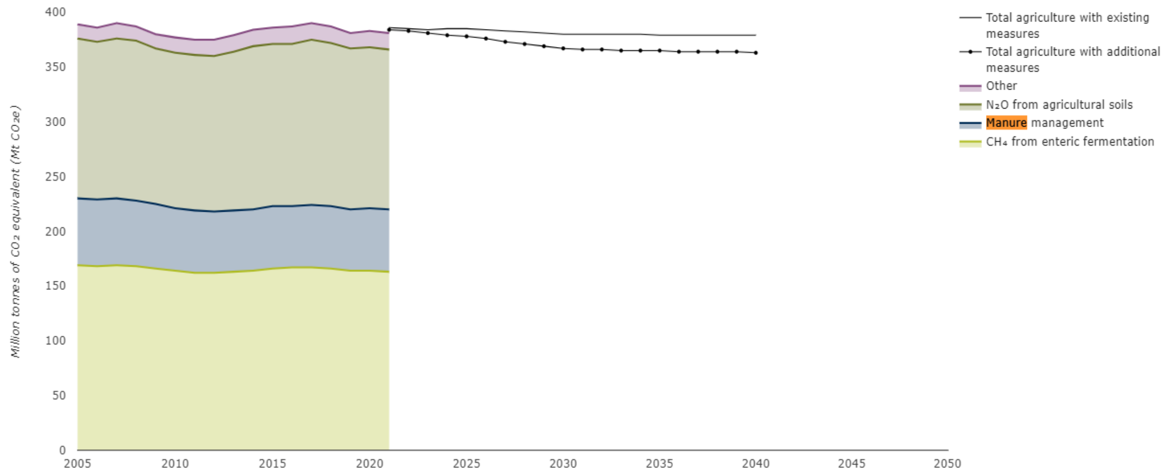

Figure 19: EU agricultural emissions by source and projected emissions

The problems of manure use, that can be addressed by manure processing, related to NPC cycles are reported in Table 37, with a qualitative estimation of the extent.

Table 37: Manure processing problems and extent

Problem	Extent of the problem
N surplus	++
P surplus	++
NH_3 emissions	+++
N leaching	++
GHG	+++
NP dependency from non-renewable source	-

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Feed dependency and food security	-
Carbon depletion/soil degradation/fertility decline	-

- no problem
+ minor problem
++ problem
+++big problem

N2C solutions tackling the CNP challenges

Within N2C, several solutions are able to tackle the main challenges that are facing the livestock industry. The Nutri2Cycle solutions able to tackle the main challenges related to manure can act according to the main strategies listed below:

- Decrease feed and NP import (DI),
- Increase the export of nutrients (IE), allowing it by processing and volume reduction.
- Improve the efficiency of the nutrient use (NU)

Table 38: solutions provided by Manure processing tackle the CNP challenges

LL number	Title of the solution	Strategy		
		DI	IE	NU
61	Tailor made digestate products (tool development)		x	x
8	Acid leaching of P from organic agro-residues in order to produce OM-rich soil enhancers and P-fertilizers		x	x
27	Use of an inoculate of microbiota and enzymatic pre-cursors to reduce ammonia emissions and optimize nutrient use efficiency in poultry manure			x
18	Slurry acidification with industrial acids to reduce NH3 volatilisation from animal husbandry			x
19	Slurry bioacidification using org. waste products to reduce NH3 volatilisation and increase fertiliser value			x
1	Ammonium stripping / scrubbing and NH4NO3 as substitute for synthetic N fertilizers		x	x
2	Ammonium stripping / scrubbing and NH4SO4 as substitute for synthetic N fertilizers		x	x
49	Nitrogen and phosphorus recovery from pig manure via struvite crystallization and design of struvite based tailor-made fertilizers		x	x
52	Pilot-scale crystallizer for P recovery		x	

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20	Low temperature ammonium-stripping using vacuum		x	x
23	Pig manure refinery into mineral fertilisers using a combination of techniques applicable at industrial pig farms		x	x
43	Pig manure evaporation plant		x	x
55	Manure processing and replacing mineral fertilizers in the Achterhoek region		x	x
40	Insect breeding as an alternative protein source on solid agro-residues (manure and plant wastes)	x		x
41	Floating wetland plants grown on liquid agro-residues as a new source of proteins	x		x
41B	Algae grown on nutrient rich liquid agro-effluents as a new source of proteins	x		x
62	Blending of raw and treated organic materials to produce organic fertilisers (NPC)			x

- LL61, LL49 Tailor-made fertilisers – The goal of tailor-made fertilisers is to provide a fertiliser that fully meets the crop requirements. Therefore, the nutrient use efficiency will be increased, and at the same time, there will be less need for additional CNP import.
- LL8 Acid leaching of P from organic agroresidues - The extraction of the phosphate from the thick fraction, through acid leaching, results in struvite, which can replace mineral P fertiliser, and an organic rich soil improver, which can be used in the region. The P-product that results from the digestion plant has the same characteristics and fertiliser performance as mineral fertiliser and can therefore serve as a replacement. The organic rich soil improver will enhance the soil biological, physical and chemical properties. Therefore, there will be mainly a decrease in CNP import.
- LL27 Use of an inoculate of microbiota and enzymatic pre-cursors to reduce ammonia emissions and optimise NUE in poultry management - The purpose of this research is to evaluate the influence of effective microorganisms on the bio stabilisation of manure before its use as a fertiliser, which can increase the nutrient use efficiency.
- LL18, LL19 Slurry (bio)acidification - Acidification or lowering the pH of pig slurry can be an effective tool to reduce gaseous ammonia and methane emissions along the slurry management chain. In terms of N, higher mineral fertiliser replacement values can be achieved and reduced N-leaching in the field has been identified, which again results in reduced environmental pressure relative to the field application of non-acidified slurry and increased yields.
- LL1, LL2, LL20, LL23, LL55: Substitution of mineral fertilisers by biobased products – These solutions are all linked to the introduction of biobased fertilisers instead of mineral ones, which can close nutrient loops at the farm level. These biobased fertilisers often have the same characteristics as its mineral counterpart, but highly contribute to a circular economy by limiting the need to produce mineral N via the energy consuming Haber-Bosch process and to import fertilisers from natural resources (like P). Currently (d.d. January 2023), these kinds of products are still considered as animal manure, and as such needs to comply with the Nitrates Directive.

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However, during several field trials their agronomic and environmental value was already proved. These solutions are able to reduce the fertilisers' costs of farmers.

- LL52 Pilot-scale crystallize for P recovery - This study aims to elucidate the effect of solids (3-4 % TS) on struvite formation in a complex matrix such as animal slurries and digestates. This study shows that the efficiency of the crystallizer prototype here used is proved as well as the use of the seawater bittern as Mg source for P removal. This study confirms the feasibility of struvite recovery and treating high total solids (TS>5%) livestock manure, which decreases CNP import.
- LL43 Pig manure evaporation plant - Refined pig manure fractions (liquid fraction after anaerobic digestion, scrubbing salt and K-concentrate) can be used as a fertiliser, e.g. to grow potatoes, which will again decrease CNP import. Additionally, the refined pig manure will have an increase nutrient use efficiency compared to pig slurry.
- LL62 Blending of raw and treated organic materials to produce organic fertilisers - The aim here is to produce blends with non-treated or treated manures, which have similar behaviour as the mineral fertiliser and a known ratio of N:P:K. Because of the blend, the nutrient use efficiency will be increased.
- LL40 Insect breeding – this solution aims to provide an alternative source for protein, by using side streams and by-products from agriculture which can be used as rearing substrate for the growth of insects depending on their nutritional value and other properties. In this solution, it was found that the insects itself can be an alternative protein and fat source, and the solid fraction of pig manure can be a good substrate for the rearing process. So this solution is also working on the challenge of protein import (e.g. soybean) by looking for alternatives, but at the same time it could also offer a solution for manure excess.
- LL41 Floating wetland plants –This solution is looking into the possibilities to recuperate nutrients from liquid agro-residues by cultivating duckweed. This small plant can convert the removed nutrients in the wetland to proteins, which can be a feed ingredient for animals due to its high protein content. As a consequence, it can substitute commonly imported protein sources. Since it can be cultivated on the biological effluent of a pig manure treatment facility, this solution can close nutrient loops on farm level.
- LL41b Algae – Similarly as LL41, algae can be cultivated on liquid agro-residues and provide alternative proteins. In this specific solution, the nutrient-rich liquid fraction of digestate was considered as a promising substrate for microalgae biomass production. Besides protein, microalgae contain diverse nutritive value compounds such as lipids, pigments, minerals, peptides, carbohydrates, antioxidants, and trace elements.

Requirements for applicability

The specific requirements for the applicability of each solution at farm level are listed in the tables below.

Table 39: Requirement for implementing solutions in Manure processing

LL61 Tailor made digestate products (tool development)
Requirement 1 A certain level of digitalization (interest in online evaluation through the tool)

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Requirement 2 Knowledge of the regional (financial) key data
Requirement 3 Knowledge of the regional legal framework
Requirement 4 Trust in the quality of the biobased fertilizers

LL8 Acid leaching of P from organic agro-residues in order to produce OM-rich soil enhancers and P-fertilizers
Requirement 1 Knowledge on the RePeat process
Requirement 2 Anaerobic digester to extract the P from the solid fraction

LL27 Use of an inoculate of microbiota and enzymatic pre-cursors to reduce ammonia emissions and optimize nutrient use efficiency in poultry manure
Requirement 1 Availability of land to form manure piles and allow the inoculate to act on the manure.
Requirement 2 Specific company structure. The company should generate sufficient manure on the farm to be able to fertilise the target plots.
Requirement 3 Specific company structure. The plots to be fertilised should be located adjacent to the livestock farm or in close proximity (<15 km), as logistics is a decisive factor for implementing the process.

LL18 Slurry acidification
Requirement 1 For in-house acidification: refurbishment of animal house to facilitate slurry acidification in the pre-tank and its recirculation in below-floor channels. Space for the sulfuric acid tank (outside building) and the controller unit (incl. pH sensor) for dosing appropriate amounts of acid. For acidification of outdoor storage tank: availability of contractor with equipment (incl. safety devices) and experience with acidifying animal slurry in storage tanks. For in-field acidification: Refurbished or new manure application tanker that includes a tractor-mounted acid tank, controller unit (incl. in-line pH-sensor), tubing and nozzles which add the acid to the slurry in-line during field application
Requirement 2 Skilled workers trained to operate the equipment and to comply with and respect safety precautions for handling strong industrial acids.
Requirement 3 Large-scale supplier of industrial grade sulfuric acid, with delivery system complying with all safety regulations, at a reasonable economic cost.

LL19: Slurry bio acidification
Requirement 1 Availability of organic residue with high contents of easily degradable carbohydrates suitable for microbial fermentation to bioacidify the slurry. Ideally, the organic residue is produced in ample quantities at the farm or locally to avoid excessive transportation costs. .
Requirement 2 Tank or other type of storage space for the residue. Some type of conservation, e.g. by ensiling, ensuring little loss of substrate quality or emissions of pollutants. Conditioning unit for premixing of residue with the slurry in pre-tank or storage tank, pH control unit for monitoring and managing bioacidification.

LL1 Ammonium stripping / scrubbing and NH4NO3 as substitute for synthetic N fertilizers
Requirement 1 The fertiliser equipment needs to be adapted to the product properties.
Requirement 2 Monitoring of every batch is important, since the concentration of the product is not always constant.
Requirement 3 The product needs to be injected.

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LL2 Ammonium stripping / scrubbing and NH4SO4 as substitute for synthetic N fertilizers

Requirement 1 The fertiliser equipment needs to be adapted to the product properties.

Requirement 2 Monitoring of every batch is important, since the concentration of the product is not always constant.

Requirement 3 The product needs to be injected.

LL49 Nitrogen and phosphorus recovery from pig manure via struvite crystallization and design of struvite based tailor-made fertilizers

Requirement 1 Specific company structure. The livestock farm should have an anaerobic digestion system in place as manure treatment technology and generate digestate that would be used as raw material.

Requirement 2 The livestock farm should have sufficient land available to install the struvite crystallisation technology attached to the anaerobic digestion plant.

Requirement 3 Specific company structure. The company should generate sufficient digestate on the anaerobic digestion plant to obtain struvite to fertilise the target plots.

LL52 Pilot-scale crystallizer for P recovery

Requirement 1 qualified staff to follow the process

LL20 Low temperature ammonium-stripping using vacuum

Requirement 1 Suitable for medium to big farms

Requirement 2 Land availability to manage the processed manure (with minor N and P content)

Requirement 3 Availability of electrical energy (preferable renewable as photovoltaic energy) and thermal energy (e.g. recovered from the heating system if it exist)

Requirement 4 Reactants supply for basification and ammonia absorption (acid)

LL23 Pig manure refinery into mineral fertilisers using a combination of techniques applicable at industrial pig farms

Requirement 1 company dimension, as high capex is needed

Requirement 2 qualified staff to follow operations

LL43 Pig manure evaporation plant

Requirement 1 The fertiliser equipment needs to be adapted to the product properties.

Requirement 2 Monitoring of every batch is important, since the concentration of the product is not always constant.

LL55 Manure processing and replacing mineral fertilizers in the Achterhoek region

Requirement 1 Product needs to mee the RENURE criteria for application

Requirement 2 Anaerobic digester for processing manure

Solution LL40 Insect breeding

Requirement 1 Investment in breeding facilities. It also requires some operational costs (e.g. energy).

Requirement 2 Analytical facilities to assess the macro-nutritional composition of insects

Requirement 3 Access to a continuous and constant agroresidues stream as rearing substrate

Solution LL41 Floating wetland plants

Requirement 1 A duckweed pond requires some area

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Requirement 2 An initial investment is necessary
Requirement 3 Reducing the duckweed's water content and contaminations
Requirement 4 Monitoring to prevent algae growth

Solution LL41b Algae
Requirement 1 ~20 m^2 available land per 500L algae cultivation capacity
Requirement 2 Own anaerobic digestion plant or be located near one for digestate supply
Requirement 3 If located in NW Europe, have or build a greenhouse to maintain optimal temperatures year round; alternatively, cultivate indoors and have access to renewable energy for artificial lighting

LL62 Blending of raw and treated organic materials to produce organic fertilisers (NPC)
Requirement 1 Accurate knowledge of original materials and consequently expedite methodologies for analysis
Requirement 2 Availability of different materials in the same farm or in a central plant
Requirement 3 Adjustment/flexibility of some local legislation

Barriers and possible booster

Barriers that may prevent the implementation and large application of the solutions are listed in the table below, together with possible boosters.

Table 40: Barriers and boosters for solutions in Manure processing

Solution	Barriers to implementation	Possible boosters to implementation
LL61	Rapidly changing market situation -> impossible to make long-term (investment) decisions Unknown, not easily accessible tool Not enough knowledge on the possibilities and quality of the biobased fertilizers	Increased online interaction & databases 1-shop-tool (as output from multiple projects) Changing market situations Changing legislation (e.g. Renure)
LL8	Investment costs. Uncertainty: Debate on reducing the number of animals can result in less manure	High costs for mineral fertilizer can boost the decision for investing in this technique. Clear strategic guidelines for the livestock sector and climate related policy
LL27	Need for agricultural machinery for frequent turning of the piles and for dosing the piles on the plots.	Information on benefits, EM solution improves the efficiency of other traditional nutrient recovery practices such as composting.
LL18	Additional costs (CAPEX and OPEX). More work (work hours to monitor in-house, or contractor for storage or in-field acidification). Potential danger of handling dangerous acid. Slurries acidified with sulfuric acid can only to a limited extent be utilised in anaerobic digestion plants for production of biogas	Environmental regulations requiring mitigation of ammonia emission from animal production to the atmospheric environment. Higher N fertiliser value (+10-15%) of acidified slurry. Stricter field fertiliser N application laws resulting in higher economic value of acidified slurry (if application of acidified slurry is not required adjusted for increased available N content). Subsidies for implementation. Coupling with S fertilization: accounting not only for N fertiliser value, but also for substituting S fertiliser from sulfate added with the sulfuric acid

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LL19	Extra work and knowledge of the bioacidification treatment. Insufficient amounts of suitable residues available for bioacidification. Difficulties and costs for adapting facilities (pH control and residue dosage/storage.) Potential adverse effects on the N fertiliser value of bio acidified slurries (due to N immobilisation).	Environmental regulations requiring mitigation of ammonia emission from animal production to the atmospheric environment. Possibility of using bio acidified slurry in anaerobic digestion plants for biogas production, typically also resulting in additional biogas yield.
LL1	Ammonium nitrate is considered as animal manure, and as such it needs to comply with the Nitrates Directive; Adapted machinery might be necessary. The product content is not constant	Legislation update
LL2	Ammonium sulphate is considered as animal manure, and as such it needs to comply with the Nitrates Directive. Adapted machinery might be necessary. The product content is not constant	Legislation update
LL49	Legislation. Currently legislation at European level and national legislation in many European countries does not allow the marketing of struvite when it comes from animal waste. Final product with a high P content, but with moderate amounts of N. Depending on the requirements of the crop to be fertilised, blending may be necessary for a higher supply of other nutrients.	Legislation update, quality standard
LL52	Price	Market rules and quality regulation
LL20	By-product commercialization (ammonia salt and calcium phosphate). Energy consumption (electrical and thermal). Availability of land in the vicinity of the farm for manure application at low cost	By-products with constant composition. Classification as RENURE Fertilizer. Recovery of waste thermal energy. Legal restrictions for application of manure to the crops
LL23	Nitrate directive	Legislation update allowing the use as mineral fertilisers, exceeding 170 kg N ha^{-1}
LL43	Missing regulation for RENURE The Business Model does not work if the material is not allowed to be used as mineral fertiliser, exceeding the limits of the Increased noise -	Legislation update
LL55	Technology showed little to no benefits compared to transportation of manure over long distance (+- 250km). Investment costs. More money can be generated by selling the C-rich product to the potting industry than to arable farmers in the Achterhoek region. Policies (max application of organic fertilizer)	Change in policy/RENURE criteria on the application of organic fertilizers. High costs of mineral fertiliser can boost the decision for investing in an anaerobic digestion plant and/or applying organic manure instead of mineral fertiliser to the soil.
LL40	High CAPEX and OPEX. Area required. Extra labour and skills required. Strict legislation	Access to credit, Legislation update
LL41	Investment cost.	Access to credit

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	Area required. Extra labour and skills required	technical support and capacity building
LL41b	Mainly legislation, currently, only plant-based digestate or from ABP cat 3 (excl. catering waste) can be used for feed production, and there is no legislation regarding algae produced on these streams Reduced volumetric capacity to treat digestate, so might be more interesting for small-scale application, even though operational costs per ton of algae produced might be higher then	If AD plant can supply not only digestate, but also CO_2 and surplus energy, the cost of production would be highly reduced and algal production could be seen as a diversification of the product portfolio of the company, making it more economically sound. Increased support for locally produced protein instead of imported protein as EU becomes more stringent in its sustainability goals. Increased need for digestate treatment as application rates become more regulated and restricted due to EU environmental goals
LL62	Acceptance of farmers. Associated costs. Issues regarding hygienic aspects	Information activities Practices to assure safety

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11. Anaerobic digestion/agroenergy Agrotypology

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Sector outline

Biogas is a gas mixture composed mainly of methane (CH_4) and carbon dioxide (CO_2), along with water and other trace gases, results from anaerobic digestion (AD). Industrial anaerobic digestion can process a wide range of biomass varieties including sewage sludge, animal and vegetable by-products, household biowaste and agricultural residues. Biogas can be converted to electricity and heat using a Combined Heat and Power unit (CHP), or it can be upgraded to biomethane, and used for a variety of end-use applications, as it can replace all the end-uses of natural gas. During the AD process, not only biogas is produced but also a valuable residual stream known as digestate is obtained. While part of the organic compounds of the initial AD feedstock are converted to biogas during the process, the mineral part remains largely in the digestate, making it an attractive soil conditioner and organo-mineral fertiliser, helping organic carbon to return back into the soil and reduces the demand for the carbon-intensive production of mineral fertilisers.

Combined biogas and biomethane production in 2021 accounted for 196 TWh of energy. According to EBA estimations, that total biogas and biomethane production in 2021 led to a total digestate production of approximately 222-258 Mt fresh matter in Europe. Both biogas and biomethane production capacities are increasing in Europe and, as it further expands, increasing amounts of digestate will be generated. Making use of its significant advantages will bring benefits to farmers, local communities, and producers. Among the different benefits, digestate allows the displacement of synthetic fertilisers, lowering their negative impact on the environment; it facilitates the sanitation of organic wastes and animal manures, it helps breaking the chain of pathogen transmission; it conveys cost savings to farmers through enhanced use of own resources and reduced purchases of synthetic fertilisers, and provides higher nutrient efficiency than undigested feedstocks such as manure, while contributing to food safety. Recycling the digestate back to soil and completing cycles of nutrients such as nitrogen (N), phosphorus (P) and potassium (K) for plants to grow is a unique benefit of digestate, which contributes to the circular economy concept. In addition, the digestate also contains relevant amounts of humus-effective carbon. In contrast to the use of synthetic fertilisers, long-term fertilisation with digestate therefore contributes to maintaining soil fertility as well as soil life and to ensuring high crop-yield lands that can be sustainably utilised (1)

According to EBA database, the end-use of digestate in Europe is its use as biofertiliser 67% of the reported countries utilise the digestate as biofertiliser, directly applied or after upgrading (solid-liquid separation, stripping, composting, etc.). In the agricultural sector, various studies reported that biogas digestate is also used as a bio-product in disease and pest control, as a substrate in hydroponic cultivation, in animal breeding, aquaculture and algae production

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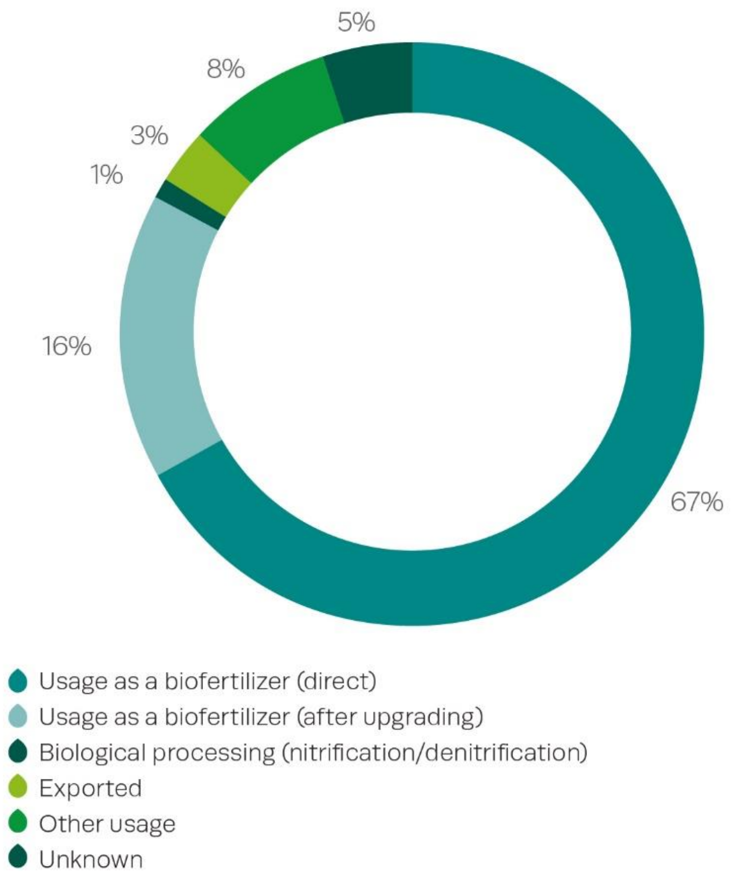

Figure 20: Digestate end-uses in Europe – Source: EBA 2022. EBA Statistical Report 2022

Table 41: Anaerobic digestion factsheet

Parameter	Unit	Value
Herd number (slurry sent to AD)	n	19,910
Turnover	€	5.75 billion
Number of AD plants in EU	n	
Agricultural area dedicated in EU	ha	Unknown
Agricultural area with nutrient surplus	%	3[1]

[1] Percentage calculated using EBA Statistical Report 2022 data on the number of biogas and biomethane plants located in Lithuania, the Netherlands, Belgium and Luxembourg, which are identified as the highest N surplus areas of Europe, according to D1.5 of Nutri2Cycle project. EBA 2022. EBA Statistical Report 2022.

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Problems and challenges of the sector related to the NPC closure

The management of digestate is one of the principal challenges of the sector related to NPC closure. It is clear that digestate has several positive characteristics to act as organic fertilizer with NPC restoring qualities; however, managing large amounts of liquid or solid digestate can be a challenge for many biogas facilities. Digestates could be either directly spread as manures or processed prior to field application e.g. by solid–liquid separation, drying, dilution or filtration. The application of different processing technologies strongly affects the digestate composition, leading to different behaviour after field application. Digestate is mainly used as biofertilizer in Europe, applied directly into the soil if biogas facilities are located near the areas of application. There is no clear digestate market at European level still, although single markets can be found between neighbours countries. As an example, an AD plant located in Ypres (West Flanders, Belgium), which treats manure, industrial wastes and other organic residues, exports part of the digestate to France. In this plant, the solid fraction of digestate is dried and composted. The proximity of the plant to many composting companies and the French border reduces transport costs, and the product containing concentrated nutrients is well accepted in northern France (Systemic Project). As the European market develops, single markets like this example are a regional solution to nutrient scarcity, contributes to nutrient recycling, an promotes local development.

The general problem of digestate management related to NPC cycles are reported in Table 42 with a qualitative estimation of the extent.

Table 42: extent of the problems related to CNP cycles in Anaerobic digestion Agrotypology

Problem	Extent of the problem
Management	+++
N surplus	+-
P surplus	+-
NH_3 emissions	+-
N leaching	+-
GHG	+-
NP dependency from non-renewable source	-
Feed dependency and food security	-
Carbon depletion/soil degradation/ fertility decline	-

- no problem
+ minor problem
++ problem
+++big problem
+-: mixed, according to specific situation

Digestate composition strongly depends on the feedstock used during the AD process, pre- and post-processing of the digestible material and reactor configuration. Thus, differences among the types of digestate are enormous and this could be a challenge in terms of application of it on different soils.

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According to the type of soil and crop needs, N and P requirements vary. Consequently, regular digestate analysis is essential for fertilizing with the amount of nutrients appropriate for plants.

Due to anaerobic digestion, 60–80% of the nitrogen is present as directly usable NH_4. This has an impact on the digestate's pH level, which is greater than that of liquid manure (about 8), increasing the possibility of ammonia emissions. Technical countermeasures must be taken in response to this, such as adapting the digestate application techniques (Möller, 2015).

Planning fertilization requires consideration of both the digestate's nutritional composition and the efficacy of the nutrients. The concentration of NH4 and the carbon to nitrogen ratio (C/N ratio) have a direct impact on the availability of nitrogen. Nitrogen is available considerably more quickly in fertilizers with a narrow C/N ratio (slurry, manure, and liquid digestate) than in fertilizers with a wide C/N ratio (compost, manure, solid digestate).

The ammonium present in the digestate is immediately available, and for this reason can support the same results and have the same efficiency of the chemical nitrogen. (Herrera et al., 2022a; Möller and Stinner, 2009; Riva et al., 2016)

There is also a component of nitrogen that is biologically bound but becomes accessible (mineralized) during the vegetative period. Nitrogen that is organically bonded is not always readily available. Only a limited portion is promptly mineralized and can be absorbed by the crops in the application year. The more tightly bonded nitrogen in the organic material mineralizes relatively slowly. Release rates of 1-3 percent of the total nitrogen per year and small N leaching, are to be anticipated, depending on the climate and the degree of soil tillage.

N2C solutions tackling the CNP challenges

The N2C solutions able to tackle the main challenges of the sector can act according to three main strategies such as depicted in WP2, D.2.6

- Decrease import of nutrient (DI)
- Increase export of nutrients (IE)
- Improve the efficiency of the nutrient use (NU)

Table 43: solutions provided by Anaerobic Digestion to tackle the CNP challenges

LL number	Title of the solution		
		DI	NU
48	Recovery of energy from poultry manure and organic waste through anaerobic digestion	X	X

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10	Small / Farm scale anaerobic digestion of agroresidues to increase local nutrient cycling & improve nutrient use efficiency	X	x
16	Using digestate, precision agriculture and no-tillage focusing on OM stocking in an area characterized by the lack of it.		X
9	Liquid fraction of digestate as a substitute for mineral N & K fertilizer		X

From the agricultural point of view, solutions to support the NCP cycles, the reduction of animal waste emissions and the adaptability of different digestate characteristics to different soils are tackled under the following: Recovery of energy from poultry manure and organic waste through anaerobic digestion; and liquid fraction of digestate as a substitute for mineral N & K fertilizer. Within these innovations it was made clear that agricultural practices which generate animal waste, if this residue is left to be naturally decomposed, associated gaseous emissions cannot be controlled and they are release to the atmosphere. Therefore, several N2C solutions included alternatives on managing animal waste which led to the avoidance of emissions being released to the atmosphere. One approach mentioned by a number of the innovations, such as LL48, centred on utilising AD for controlling emissions from animal wastes, as they are fed into AD plants and emissions are contained and harvested to produce energy reach biogas. Additionally, innovation LL8 also tackled the possibility of enhancing soil organic matter, as, through its associated 'RePeat' system an organic matter rich by-product is created after AD of livestock waste. This product can be used as a new form of soil conditioner, supporting nutrient recycling and regenerative agriculture practices.

Regarding N2C solution LL9, liquid fraction of digestate as a substitute for mineral N & K fertilizer, the outcomes of the experimental trial in Flanders, Belgium, have demonstrated that the liquid fraction of digestate contains almost all nutrients as they were present in the ingoing feed, but more mineralized. Therefore, digestate from AD was proven to be suitable as fertilizer, and, after an extra separation step, the liquid fraction of the digestate could be used as an alternative for mineral N fertilizers. When the separation step is being done thoroughly, this even has the potential to be classified under the RENURE criteria. For the moment, however, it is still considered as animal manure under the European legislation, as it is treated as animal by-product.

Apart from the positive environmental effects, the responsible optimisation of nutrient management, can certainly be associated with a reduction in costs for an AD plant owner. This could lead to monetary advantages for the plant operator when high-priced mineral fertilizers are replaced, or new marketing channels are opened up. For some countries like Ukraine, Czech Republic or Estonia, digestate still represents a cost rather than an income for many plant units. An optimized management of digestate and the development of a market are therefore needed. The optimized management of digestate, and it associated solution for NPC challenges, can be tackled with innovations such as LL16, precision agriculture and no-tillage techniques, focusing on OM stocking in an area characterize by the lack of it, which also allows for the creation of a market and an added value for plant owners and farmers. Outcomes from this solution experiments have shown that digestate can be seen as a good

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and sustainable fertilizer by recovering nutrients from wastes and helping close nutrient loops in view of a circular economy.

Requirements for applicability

The specific requirements for the applicability of each solution at farm level are listed below

Table 44: Requirements for implementing solutions provided by Anaerobic Digestion

Solution 48 Recovery of energy from poultry manure and organic waste through anaerobic digestion
Requirement 1 Feedstock availability (manure and organic waste)
Requirement 2 Correct management of organic waste for facilitating its availability
Requirement 3 Logistics on transport of feedstock to anaerobic digestion plant
Requirement 4 Anaerobic digestion plant, including functional installation, equipment and personnel

Solution 10 Small / Farm scale anaerobic digestion of agroresidues to increase local nutrient cycling & improve nutrient use efficiency
Requirement 1 Farm scale biogas/biomethane digester, including all technological requirements for its optimal functioning
Requirement 2 Agroresidues availability and correct management for its use as feedstock in the AD process
Requirement 3 Surrounded land area available for the direct application of digestate as fertilizer

Solution 16 Using digestate, precision agriculture and no-tillage focusing on OM stocking in an area characterized by the lack of it.
Requirement 1 Digestate availability, based in two possibilities: a) obtained from close-by AD plants; or b) obtained from a distant biogas plant, which has upgraded the digestate to facilitate digestate transport
Requirement 2 Defining soil requirement for optimizing precision agriculture techniques, which includes the availability of adequate equipment
Requirement 3 Identification of lands with lack of organic matter, based on soil, weather and environmental conditions analyses.

Solution 9 Liquid fraction of digestate as a substitute for mineral N & K fertilizer
Requirement 1 Digestate production obtained from a biogas/biomethane plant
Requirement 2 Upgrading and conditioning technologies for digestate (liquid – solid separation)
Requirement 3 Available land for the application of liquid fraction of digestate (complying with surplus areas regulation)

Barriers and possible boosters for implementation

All aforementioned solutions (48, 10, 16 and 9) share barriers for its implementation/deployment. Definer barriers and their possible drivers are described below.

Table 45: Barriers and boosters for solution provided by Anaerobic Digestion

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Barriers	Possible booster
Digestate still unknown to several sectors	Increase initiatives to disseminate the positive externalities of the production of biogas/biomethane on rural development and agriculture including agro-ecological intensification based on sequential cropping and nutrient recycling with digestate.
Feedstock availability and feedstock management	Overcoming restriction and current lack of economic and policy drivers for feedstock mobilization in the EU (an incomplete and un-updated Annex IX of the RED II , for example)
Poor waste management in several cities of Europe hinders its valorisation through AD	Municipalities treating source separated waste and sewage water can create new local jobs, while at the same reducing their utility expenses or even bringing in new revenues from selling biogas, biomethane and organic fertilisers.
Lack of a legal framework	Many European countries do not have appropriate (if any) legislation concerning digestate, resulting in legal barriers to the use of waste material, its conversion into products or its export abroad. To solve this issue across all member states, it is essential to revise the current regulations that affect digestate: EU Fertilisers Directive, wastewater management directive, etc.
Lack of information	Public authorities should make a conscious effort to explain to farmers, policy makers and civil society, the advantages of digestate and the adequate management of local resources to build confidence on its use.

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SYSTEMIC H2020 EU-project. Facsheet SYSTEMIC demonstration plant. Waterleau NewEnergy (Ypres, Belgium)

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12. By-product processing Agrotypology

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Sector outline

The agro by-products derived from integrated crop-livestock production systems play a significant role in sustainable agri-food and energy systems. These by-products are of various types and can be classified into different groups, such as by-products from fruit and vegetable processing industry, crop waste and residues, by-products from sugar, starch and confectionary industry, by-products from distilleries and breweries, by-products from grain and legume milling industry, and by-products from oil industry and residues from dairy industry. The handling and technologies used for processing of by-products are generally based on their type (Ajila et al., 2012).

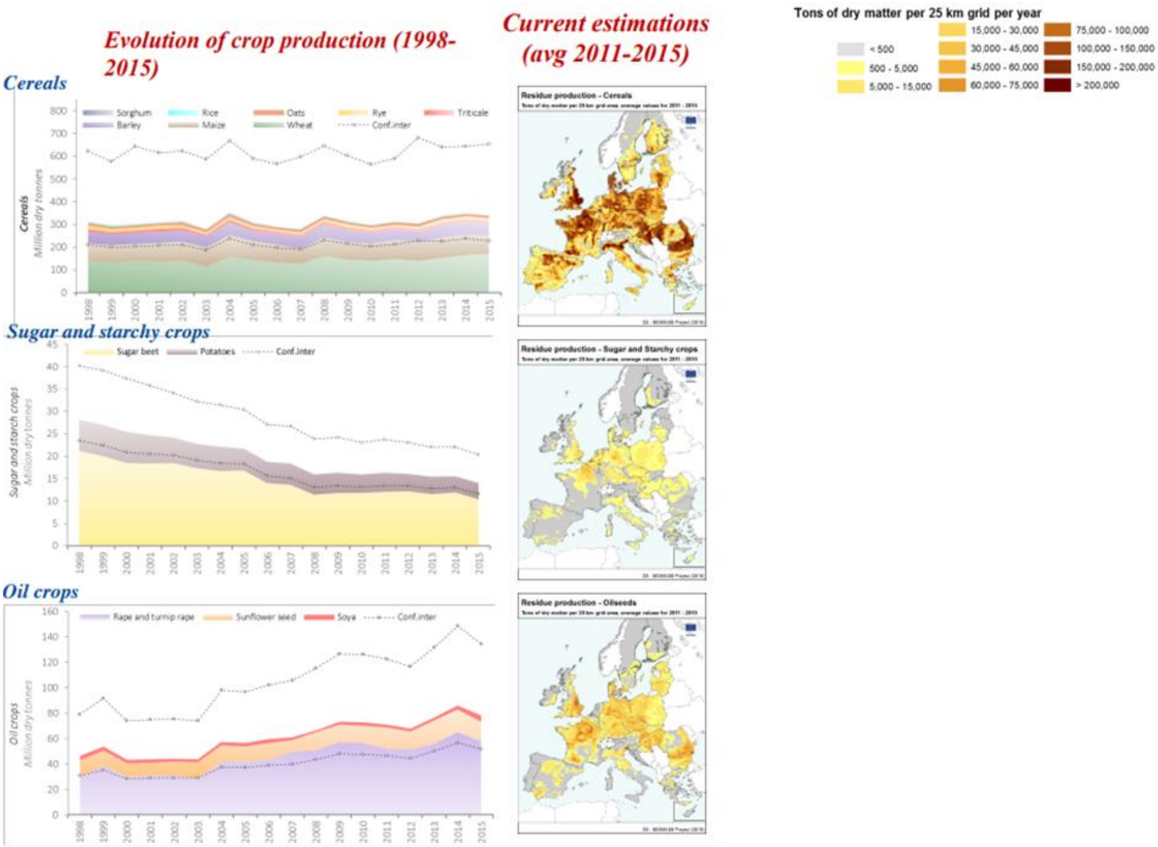

Figure 21: Evaluation of crop production and estimations on crop residues in Europe (Sara García-Condado et al., 2017).

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These products usually represent relatively high amounts of cellulosic material that could be returned to the soil for its future enrichment in carbon and nutrients or could be made available for further conversion to biofuels, bioenergy and other products. Crop residues are also an important low-cost feed resource for animals. Technologies needs to be developed for better utilization considering factors, such as characteristics of individual wastes and the environment in which they are produced, reprocessed and utilized. Such technologies need to convey products that are safe not only for animal feed use, but also from the point of view of human feeding (Mutwedu et al., 2020; Tiwari and Khawas, 2021).

Table 46: by-product processing factsheet

Parameter	Unit	Value	Reference
Amount of material	tons	439 M	
Possible estimated Turnover	€	-	
Number of companies involved in processing at present	n	-	
Potential agricultural area: arable land	ha	85-90M	Eurostat

Problems and challenges of the sector related to the CNP closure

The problems of agro by-products related to NPC cycles are reported in table 11.1, with a qualitative estimation of the extent. The treatment of by-products is indeed a way to solve problems coming for others agrotypology, mainly (as volume of production) cereals and maize, vegetables and orchard.

Table 47: extent of the problems related to CNP cycles in By-product processing

Problem	Extent of the problem
N surplus	+-
P surplus	+-
NH_3 emissions	+++
N leaching	+++
GHG	+++
NP dependency from non-renewable source	-
Feed dependency and food security	-
Carbon depletion/soil degradation/ fertility decline	-

- no problem or helping to solve
+ minor problem
++ problem
+++big problem
+-: mixed, depending on the contextual situation

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The major challenges of the sector in terms of NPC cycles are:

Nutrient leaching via crop residues: The release of available N from crop residues can be beneficial for increasing crop yield in the next growing season, but only if it is not lost from the soil beforehand. However, residue decomposition can create anaerobic hotspots in the soil, which may stimulate denitrification, partially thwarting the benefit of soil C sequestration. Crop residues with C:N ratio greater than 25 are usually more recalcitrant and force microorganisms to take up N from soil to meet their N needs, i.e., the decomposition of crop residues with a high C:N ratio causes subsequent microbial N immobilisation. Therefore, the temporary shortage of soil N might restrict nitrification and denitrification, with beneficial effects on NO_3^- and N_2O losses (Li et al., 2021). Nutri2Cycle addresses this challenge via "LL34 Secondary harvest: additional valorisation of crop harvest and processing residues".

Vegetable crop residues are usually incorporated into the soil shortly after the harvest in order to minimise the risk of infection by plant pathogens such as damping-off diseases and downy mildew in crop rotations. However, crop residues are often characterised by a low C:N ratio which accelerates net mineralisation and nitrification after incorporation into the soil. Consequently, the N concentration sharply increased after harvest concentration, and catch crops are usually grown during the winter leaching period (Frerichs et al., 2022), which is addressed by LL21 "Catch crops to reduce N losses in soil and increase biogas production by anaerobic co-digestion" in Nutri2Cycle.

Nutrient losses: Soil erosion reduces the agricultural value of lands via physical-chemical degradations. Soil nutrient loss through runoff and sediment is a major driver for soil fertility decline. The eroded sediments or soil are highly concentrated with crop nutrients, which are washed away from farmlands. Catch crops are fast-growing crops that are grown between two main crops, which allow for retaining part of the remaining nitrogen into soil since the catch crop absorbs part of the remaining nutrients to grow up. Furthermore, the catch crop protects the soil from erosive phenomena and against the formation of the soil crust, improves the habitat of the micro-wildlife and increases the landscape diversity. Subsequently, this catch crop can be incorporated into the soil in the form of green fertiliser, or be destined to other uses, such as co-digestion with livestock manure. Anaerobic digestion plants that treat livestock manure usually use co-substrates to increase biogas production, due to the low carbon to nitrogen (C/N) ratio of livestock manure. The use of a carbon-rich co-substrate improves substrate characteristics and compensate its carbon deficiency. Thus, the co-digestion of catch crops with livestock manure improves C/N relation of the anaerobic digestion substrate and the subsequent biogas production. Nutri2Cycle addresses this nutrient management aspect via LL21 "Catch crops to reduce N losses in soil and increase biogas production by anaerobic co-digestion".

Nutrient management: Phosphorus is essential for all life and all efficient agricultural food production. No Phosphorus availability results in no food production. On the other hand, N fertilisers are produced via the Haber-Bosch process which is energy intensive. Several nutrient management solutions can

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easily tackle nutrient recovery and recycling from agro by-products to minimise the reliance on chemical fertilizers.

The dairy systems are large users of supplemental grain based feeds and the European dairy-industry is the largest in the world accounting for 22% of global milk production. This industry through processing of milk and dairy products generates large volumes of nutrient rich sludge. For example in Ireland the dairy processing industry generates circa 126,718 tonnes of this sludge annually. Recent work by Ashekuzzaman et al., (2021) shows that these dairy residues contain substantial levels of crop nutrients. For example N ranged from 20 – 57, P ranged from 15 - 70 and K ranged from 2.9 – 7.2 g/kg dry weight respectively. To close loops in C, N and P cycling it is important to return these nutrients to the croplands. Crop farmers are very sensitive to the nutrient feed out profile and available nutrients in bio-based materials as overestimation of nutrients can lead to reduced yields. Under estimation can lead to crop lodging. Nutri2Cycle engages with a crop farmer to use these materials and to research and demonstrate the opportunities for C, N and P loop closure by integration of a suite of organic manures/residues into an arable crop rotation via the solution "LL17 Crop farmer using a variety of manure and dairy processing residues to recycle and build soil C, N, P fertility".

The animal by-product rendering industry processing large amount of animal bones for production of gelatine, pet-food, bone china and bone grist. The bio-origin animal bone is of apatite origin, therefore containing a higher concentrated Phosphorus content than its mineral version. The only phosphate mineral natural resource with high Phosphorus concentration on this Planet Earth in industrially and economically available scale is the apatite mineral, which is having two major natural forms, mineral phosphates and bio-origin animal bones. The Nutri2Cycle solution "LL22 BIO-PHOSPHATE: high temperature reductive thermal process recovery of concentrated Phosphorus from food grade animal bones" is a phosphorus recovery and carbon refinery system as a purposely designed and specific carbonisation system with zero emission performance with interlinked wide range of BIO-NPK-C formulations, incl. biotechnological formulations as well.

Digestate is an excellent fertiliser containing all nutrients and micronutrients necessary for modern farming, including Nitrogen, Phosphate and Potassium. Since no nutrients are lost during AD, farmers can close the nutrient cycle and reuse these vital minerals. Additionally, organic matter in digestate can build up the humus content in the soil; this is a benefit unique to organic fertilisers which is particularly crucial for arid and semi-arid lands with low carbon content. In that sense, Nutri2Cycle propose various solutions for digestate valorisation management including "LL16 Using digestate, precision agriculture and no-tillage focusing on OM stocking in an area characterised by the lack of it"

N2C solutions tackling the NPC challenges

Solutions applicable to the by-product processing agrotypology, use the following strategies to effectively address the nutrients loop

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- Improve the efficiency of nutrient use (NU),
- Allow the recovery (and export EX) of nutrients from nutrient-rich sectors back to agriculture

Table 48: solutions provided by By-product processing to tackle the CNP challenges

LL number	Title of the solution	Strategy	
		EX/I	NU
16	Using digestate (from organic wastes), precision agriculture and no-tillage focusing on OM stocking in an area characterized by the lack of it	x	x
17	Crop farmer using a variety of manure and dairy processing residues to recycle and build soil C, N, P fertility	x	x
21	Catch crops to reduce N losses in soil and increase biogas production by anaerobic co-digestion		x
22	BIO-PHOSPHATE: high temperature reductive thermal process recovery of concentrated Phosphorus from animal bones	x	x
34	Secondary harvest: additional valorisation of crop harvest and processing residues		x

Requirements for applicability

The specific requirements for the applicability of each solution at farm level are listed in the table below.

Table 49: Requirements for implementing By-product processing solutions

The specific requirements for the applicability of each solution at farm level are listed below

LL16 Using digestate, precision agriculture and no-tillage focusing on OM stocking in an area characterized by the lack of it
Requirement 1 company dimension, large structure able to solve complex compliance requirements
Requirement 2 long-standing trust from the local farmers, otherwise no one would accept the distribution of digestate from urban sludge

LL17 Crop farmer using a variety of manure and dairy processing residues to recycle and build soil C, N, P fertility
Requirement 1: Crop farmers interested in incorporating bio-based fertilisers into crop nutrient management plans
Requirement 2: Access to animal manure and dairy processing sludge fertilisers
Requirement 3: Analysis of manure and dairy processing sludge to determine specific nutrient content
Requirement 4: Recent soil analysis of receiving lands in order to determine soil P index & soil K index

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Requirement 5: Development of an appropriate nutrient management plan for given crop, under given soil conditions with known nutrient values of bio-based fertilisers
Requirement 6: Equipment & skillset to successfully apply animal manures and dairy sludge on cropland

LL21 Catch crops to reduce N losses in soil and increase biogas production by anaerobic co-digestion
Requirement 1: Availability of a biogas plant to introduce catch crops as a co-substrate.
Requirement 2: Land availability to manage the digestate.
Requirement 3: Catch crops characteristics: capability to retain nutrients (and heavy metals), resistant to low temperatures, rapid growth, etc.
Requirement 4: Frost period should be short enough to allow Catch Crops to grow and have a reasonable production (biomass) to "catch" the nutrients and enable their use as a co-substrate (economic viability).

LL22 BIO-PHOSPHATE: high temperature reductive thermal process recovery of concentrated Phosphorus from food grade animal bones
Requirement 1: Medium scale industrial installation with zero emission and energy independent processing performance
Requirement 2: Medium scale of industrial operation is at 20,800 t/y that is operated by SME company dimension

LL34 Secondary harvest: additional valorisation of crop harvest and processing residues
Requirement 1: Need for sufficient volume of the material (both for the investment and the value creation afterwards)
Requirement 2: Material as homogeneous as possible
Requirement 3: End-users with an interest in the use of the processed residues
Requirement 4: Full sanitation of the animal by-product material to prevent the risk of cross-contamination

Barriers and possible boosters for implementation

Table 50: Barriers and boosters in implementing By-product processing solutions

LL16 Using digestate, precision agriculture and no-tillage focusing on OM stocking in an area characterize by the lack of it	
Barriers	**Possible booster**
Bureaucracy	Simplification of permissions
Distrust and misinformation	Information activities, absence of conflict at the local political level

LL17 Crop farmer using a variety of manure and dairy processing residues to recycle and build soil C, N, P fertility	
Barriers	Possible booster
Ability to source animal manure and dairy processing sludge	Reduced reliance on synthetic fertilisers

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Cost of transporting manure and sludge from source points to cropland	Compliments E.U. legislation relating to circular economy and reduced reliance on imported chemical fertilisers
Knowledge of nutrient value of both manure & sludge treatments	Improves soil health/ soil organic matter content within croplands
Ensuring correct application rate & method used on cropland	Additional use for animal manures & by-products of dairy processing industry
Applicability of treatments within nitrate vulnerable zones	

LL21Catch crops to reduce N losses in soil and increase biogas production by anaerobic co-digestion

Barriers	Possible booster
The need of a biogas plant to use the catch crops as a co-substrate	Legislation on sustainability considering the need for co-digestion

LL22 BIO-PHOSPHATE: high temperature reductive thermal process recovery of concentrated Phosphorus from food grade animal bones

Barriers	Possible booster
Medium scale CAPEX investment cost	Access to credit Customised formulations according to User's need

Secondary harvest: additional valorisation of crop harvest and processing residues

Barriers	Possible booster
Significant costs for selection of the “good” material	High disposal costs of the raw residues
Contamination (dirt, stones, plastics, ….) can have an impact on the quality	Legal framework that doesn’t allow to leave the harvest residues on site
Economic feasibility (impact of scale)	Low price and local input source
Fragmentation in parcels of land	Local district initiatives, Information, technical support, aggregation to share equipment's and maximise outcomes
High content of sand (sugar beet) that uses the pumps, valves etc and gives a sedimentation in the digesters	supply chain development and market availability of better equipment's

Tailor made digestate products (tool development)

Barriers	Possible booster
	Increased online interaction & databases
Unknown, not easily accessible tool	1-shop-tool (as output from multiple projects)
Rapidly changing market situation -> impossible to make long-term (investment) decisions	Changing market situations
Not enough knowledge on the possibilities and quality of the biobased fertilizers	Changing legislation (e.g. Renure)

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13. Potential of solutions to be implemented and improve CNP closure. A multi criteria approach

Solutions investigated In the N2C project included diverse approaches and different steps of the nutrient processing cycle, in order to have a wide angle on the CNP challenges and on the potential opportunities.

The multi-criteria analysis (MCA) is proposed in the context of the N2C project, to provide an overall synthesis of the investigated solutions, considering the problems to be solved, the perception of the stakeholders involved, and, nonetheless, the challenges related to specific geographical constraints, such as local air pollution (Catalunya and Po valley district) or water quality.

The analysis is not intended to select solutions or to identify "the best ones", as baselines, problems and contexts are different, but to identify clusters that require common support policies, or clusters that offer solutions to specific contextual problems (local impacts on water or air). Consistent with this goal MCA does not replace more detailed analyses such as Life Cycle Assessment (LCA) or Cost-Benefit Analysis (CBA), rather, it provides a simple overview of the areas of improvement or deterioration compared to the baseline and identifies clusters across solutions.

In Figure 22 is reported the workflow and the constraints related to the synthetic delivery of information in the white book and MCA.

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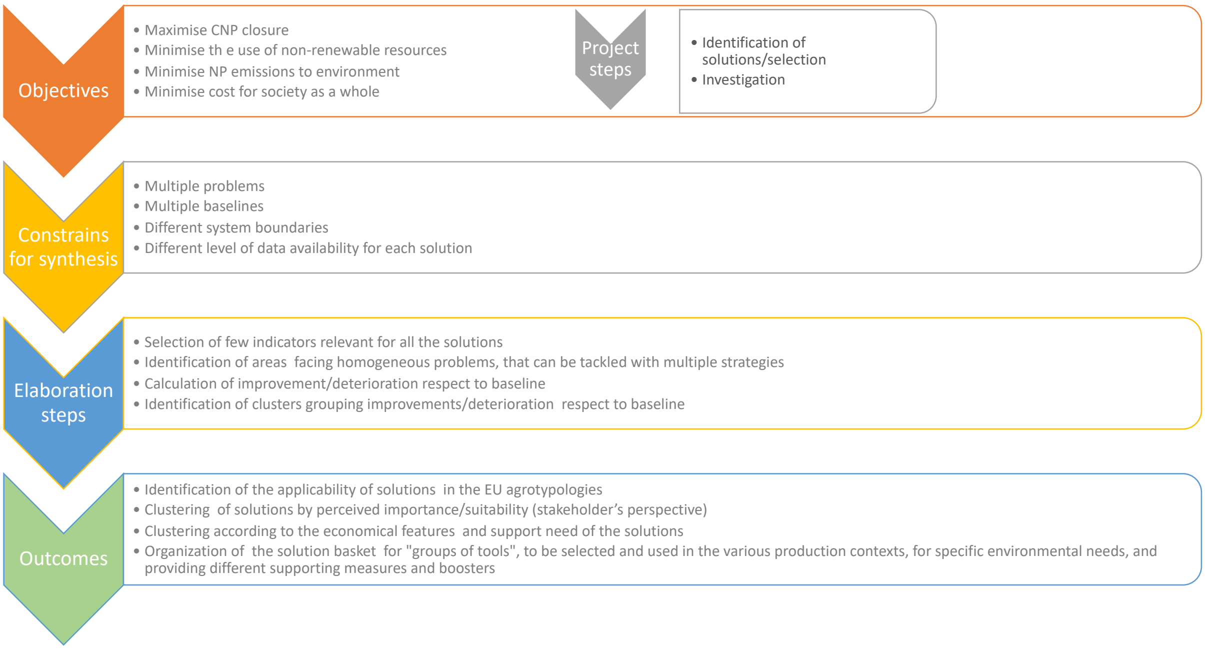

Figure 22: process flow of MCA

As a general frame, Multi-Criteria Analysis (MCA) deals with situations where multiple criteria or objectives are involved and where a single criterion or objective cannot be used to achieve a complete understanding of the action to select. It is a knowledge synthesis method that supports a comprehensive understanding of different alternatives, by systematically exploring their pros and cons and revealing trade-offs (Cinelli et al., 2014), as alternatives are compared against a set of explicitly defined criteria that account for the relevant aspects of the topic under investigation. Its main strength is that it combines the analytical performance of the alternatives with the priorities of stakeholders or contextual constraints in a transparent and replicable way and in a simple and straightforward fashion and as such it is extremely useful for framing and structuring complex problems (Dean, 2020). For these reasons, MCA has been increasingly used in environmental decision-making to support the identification of suitable courses of action by integrating factual information and impact modelling, with information collected through stakeholder engagement or priorities set by contextual constraints (Acosta and Corral, 2017; Nordström et al., 2011).

Besides the overview of single advantages and drawbacks, MCA allows assigning different weights to indicators in specific areas of interest, such as the economy, global environment, and local environment, according to specific contingent priorities and stakeholders' perspectives. This allows for a layman's understanding of which solutions are best suited to specific areas and which interests must be balanced and eventually corrected/supported. The solutions are finally organized in economic

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and environmental clusters in order to have a selection grid to choose the best tool in each production and environmental context. combined with the best support measures.

14.Problems, contexts, and strategies across the agrotypologies

Livestock agrotypologies and nutrient-rich areas

The description of the agrotypologies CNP-related problems and the strategies to tackle the problems have highlighted that livestock agrotypologies (pig, poultry and cattle) are mainly related to problems of surplus of nutrients, due to the import of feed and concentration of animals in restricted and limited areas of high zootechnical intensity. Nutrient overload may cause in turn, mismanagement and ultimately harmful impacts on the environment. The strategies in these areas (nutrient-rich areas) are mainly to i) decrease the import of feed and nutrients, ii) support the export of nutrients and iii) make the use of nutrients more efficient in all possible ways, decreasing ineffective distributions and environmental impacts.

Non-livestock agrotypologies and nutrient-poor areas

On the other hand, other agrotypologies (vegetables, orchard, agroforestry and to some extent the production of cereal and maize, when far from livestock production) face different challenges, such as the lack of organic matter and nutrients, the reliance on non-renewable nutrients, the energy and cost to produce and use synthetic fertilizers. These agrotypologies, mainly present in so-called "nutrient-poor" areas, are using other types of strategies to cope with the CNP challenges, such as i) the import of organic nutrients from other geographical areas or sectors (wastewater, sludge, agri-food wastes). Related to the import and the use of organic renewable nutrients comes the need to increase nutrient efficiency, as for the livestock agrotypologies, to decrease costs and impacts on the environment.

Based on these different problems and strategies, needed to tackle the CNP challenges in the different agrotypologies, the solutions are discussed in 2 different groups

- solutions applicable to the problems of the livestock and nutrient-rich areas,
- solutions applicable to nutrient-poor areas

with some overlapping related to solutions mainly focusing on the increase of nutrient efficiency, which could indeed be applicable in both areas.

In Figure 23 are reported the areas in Europe with high and low livestock unit, (nutrient-rich, nutrient-poor and what is in the middle areas) and on the other map the N and P load due to manure surpluses.

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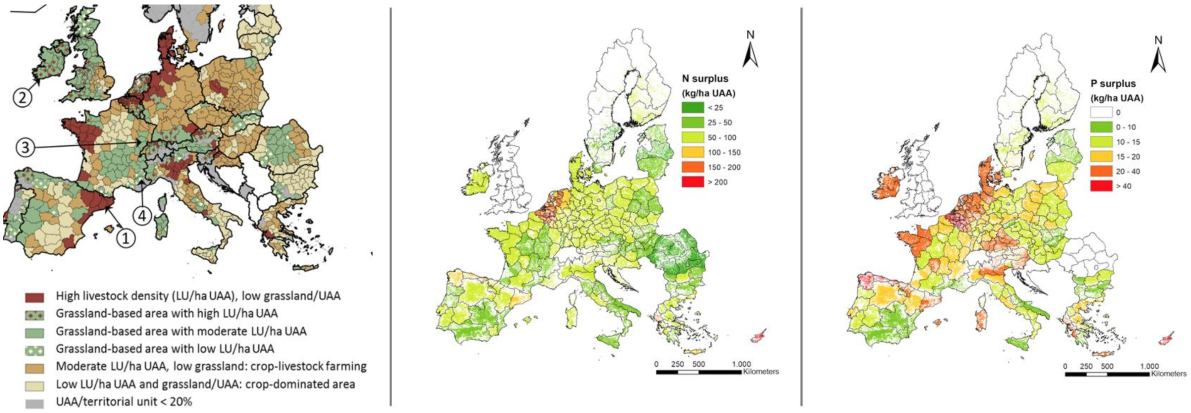

Figure 23: EU areas with livestock agrotypologies (livestock density, (Dumont et al., 2019) and nitrogen load from manure.

The problems of the two areas are different and for this reason, also in the MCA, the two areas will be presented in two sections, each displacing the specific solutions and the different clusters that emerged from the analysis

15.Method

Criteria and indicators

The selection of criteria for a multicriteria analysis depends on the objectives of the analysis. In the case of managing nutrients in agriculture and closing CNP cycles, the objectives of the analysis must include reducing the negative impacts of nutrient management on the environment (improve the efficiency of nutrients and reduce losses, (Figure 24) and improving the economic viability of agricultural practices (Hayashi, 2000).

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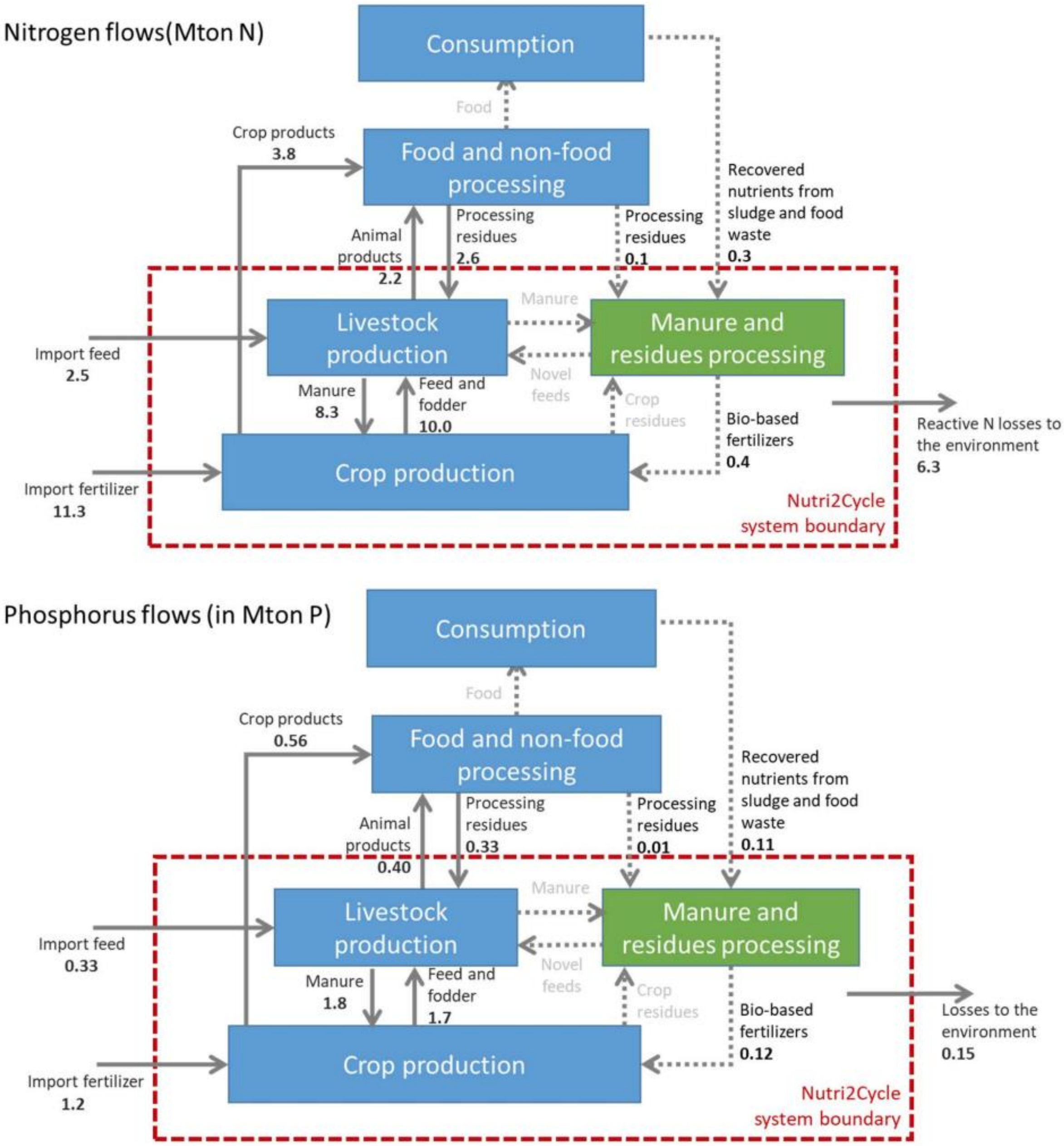

Figure 24: nitrogen (upper figure) and phosphorus (lower figure) flows (in Mton N/P) in the food system (based on van Dijk et al., 2016). Inputs, use and losses.

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The criteria proposed for the MCA include indicators for local (air and water quality on-site) and global impacts (GHG emissions) and indicators for the global cost, i.e. CAPEX and OPEX and energy consumption/recovery.

- Environment local impacts
- Environment global impacts (GHG)
- Economy (energy and costs)

The first criterion, impacts on the local environment, is relevant because nutrient and slurry management practices can have significant effects on local air and water quality. Emissions of ammonia and other gases from manure storage and application cause pm 10 and 2.5 increase and odours. Excess nitrogen from fertilizer and manure can leach into waterways, leading to poor drinking water quality and health problems (Biernat et al., 2020). Recent studies (Herrera et al., 2022b; Leip et al., 2022, 2015) and the core of N2C experimentation (D.2.6, D2.5) have shown that improved management practices of recovered nutrients can reduce these impacts on local environments. The indicators relating to local impact partially touch the area of social sustainability (Fairburn et al., 2019; Rafaj et al., 2018), as local impacts are often linked to low acceptability of new production models or innovations (Belzile et al., 2009; Ekane et al., 2021) .

The criterion related to GHG is always to be considered, as agriculture is a significant contributor to greenhouse gas emissions (Reay et al., 2012) and as Global Warming is going to affect economy and decisions at each level of action in the near future.

Finally, the criterion of economic sustainability is needed as farmers and agricultural businesses need to be able to implement nutrient and slurry management practices in a financially viable way. This includes considering the energy consumption associated with different practices, as well as the operational and investment costs. Thus, the economic area is to be considered and weighted.

The social criteria (measured by indicators such as suitability of the supply chain for stakeholders, farm size suitability, new job positions, employee training and increase in traffic and noise) is not included in the calculation of the synthetic numerical score. This choice was due to the fact that the evaluation (based on Likert scale) is often flattened on the higher part of the scale (all solutions exerting positive social effects), thus causing the aggregated score to be less incisive and descriptive. Specific items or remarks reported by the experts during the evaluation will instead be reported in the discussion of the various cluster, thus highlighting, if they exist, the specific issues that differentiate and characterize some solutions.

The criteria are consistent with the ones used in D3.1 (Emissions to environment, Resilience to climate change and Use of primary resources), although categorized in a slightly different way, in order to effectively represent interests prioritized differently by different stakeholders (local issues versus citizens and local administrators; global issues versus regional and supranational policies, see the

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weighting option paragraph). Finally, the saving of primary resources is considered as the foundation of all the solutions, as they are all designed to close the NPC cycles (saving non-renewable resources), therefore in this analysis, the attention is primarily aimed at verifying the environmental and economic cost/benefit of this saving.

The 3 main criteria and the indicators used are reported in detail in Table 51

Table 51: Criteria and indicator used in MCA

Criteria	Indicator		Explanation
Environment local	Nutrient balance in the area	Reduction of N and P import by feed (also related and aggregated in graphical presentation with primary production)	This indicator quantifies the extent of the reduction of N (and P) import through feed coming from extra livestock areas (i.e. import of N from oversea soy). It evaluates the effectiveness of nutrient load reduction strategies (reduced import) in areas with high livestock intensity.
	Air quality,	Direct ammonia emission	Ammonia emissions
	Water quality	N (N leaching)	Nitrate leaching
	Water quality	P (over) application	Accounts for the P overapplication respect to plant needs
	Soil quality	Carbon delivered to soil	Account for the difference in carbon delivered to soil
Environment global	Climate	Direct GHG emissions	Direct emissions of GHG (methane and N_2O expressed as CO_2 equivalents) in baseline and in solution
		Energy recovery	Recovery of renewable energy
Economy	Efficiency	Energy demand	Energy demand in baseline and in solution
	Financial sustainability	Costs capex and opex	Costs in baseline and in solution

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	Feed and feedstock security	Primary production and reduction of NP import by feed	Primary production in baseline and solution (it is relevant for solution improving productivity or getting a new biomass from waste).

Excluded metrics: only direct emissions of the core process included in the baseline and solution were selected, while upstream process emissions were not. This is due to the specificity of the objectives of the multi-criteria analysis: highlighting conflicting interests and needs in a simple way rather than having exhaustive analyses. Furthermore, direct emissions, as well as energy consumption, are core elements of technologies, while upstream processes could change over time (i.e. energy production and related emissions) and finally, a proxy of upstream processes is provided by the operating costs and energy demand.

The cost of labour was not included in the cost category (OPEX), both due to the difficulty of an accurate estimate for many low-TRL solutions (tier 1) and also because it is an indicator that can be interpreted in conflicting ways, as a cost but also as an opportunity (job creation and social cohesion).

Stakeholders and weighting options.

The stakeholders represent different groups of people who have an interest in the management of nutrients and slurry in agricultural systems. Each stakeholder has a different perspective and set of priorities, which are considered in the set of weighting options used to frame the groups of technologies.

Main stakeholders: farmers and citizens

Farmers: are the agents that implement and deploy solutions, they are directly impacted by the costs and benefits of these technologies (Lissaman et al., 2013) and may have important insights about the implementation of solutions (Albizua et al., 2021; Dessart et al., 2019; Liu et al., 2019). As outlined by FG (Focus Group) results, the criteria and needs of concern for this stakeholder group are the costs, the financial risk and the initial investment, the productivity and efficiency (energy demand), consistent with previous findings (Duong et al., 2019).

The detection and elaboration of stakeholders' perspectives with respect to solutions to close CNP cycle, was performed in a large and comprehensive fashion during task 5.1, and results are presented in D5.4. For the purpose of MCA, the hierarchical order of preference of the criteria, highlighted for the two types of stakeholders, was considered to elaborate the weighting sets.

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The criteria order of preference selected by the production side (farmers) and the demand side (consumers/citizens) are presented in Table 52 and Table 53respectively (see D.5.5 for more details).

For the purpose of elaborating the weighting set, only the share of preference reported for economic and environmental criteria was considered (the social criteria not being included in the numerical calculation). The Farmer perspective weighting set (economic Perspective) was built in order to have 63% of the weight on economic indicators and 37% on the environmental ones.

Table 52: Production side preference

Criteria	Motivation	Share of preference
ECONOMIC	The adoption of the innovation is accompanied by SUBSIDIES The innovation will REDUCE the FARM COST The COST OF THE INNOVATION (Initial investment) The innovation will INCREASE the farm's PRODUCTIVITY Transmit the cost of the innovation to the sale price by MARKET LAB The innovation is NOT a FINANCIAL RISK	**63%**
ENVIRONMENTAL	The innovation will improve the COMPLIANCE with environmental Rl The innovation will REDUCE the farm's WATER use The innovation will reduce the farm's ENERGY CONSUMPTION The innovation will REDUCE the AMOUNT Of slurry and manure The innovation will REDUCE farm's unpleasant ODOURS Replace SYNTHETIC fertilizers by ORGANIC one	**37%**

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Table 53: Demand side preference

Criteria	Motivation	Share of preference
Economic	A1. Investing in technology and modernization A2.Grow the improved varieties (increase productivity) A3. Ensuring food supply A4.Diversify their market (clients) A5. Growing native varieties (low productivity)	**44%**
Environmental	C1. Reduce water consumption C2. Reduce the use of synthetic fertilizers and favour organic fertilizers C3. Respect animal welfare C4. Generate less waste C5. Reduce greenhouse gas emissions	**56%**

Citizens and consumers are an important stakeholder group (Verhees and Verbong, 2015) as they are the ones who live in the vicinity of agricultural land and may be directly affected by the impact of agricultural practices on air and water quality. Moreover, they orient somehow the production chain by their purchase.

According to the FG's results, consumers/citizens declare to be mainly concerned about the impact of agriculture on climate change. Since this was the only question related to the impacts of agriculture on the environment and there were no questions distinguishing aspects of local and global impact, the preference was interpreted as a proxy for indicating the possible effects on the environment (both local and global impacts) of agriculture. Therefore, also the criteria of air quality and water quality are deemed to be of particular interest to them. References showed (Hite et al., 2002) that citizens are likely to support policies that protect water quality and the environment, even if resulting in higher costs for farmers.

Other stakeholders, namely groups, hold vision and promote action with respect to nutrient management. For them it was not possible to detect clear perspective, but it is important to have a qualitative taste of the driving forces.

Groups involved in mediation, solutions and prioritization of interests. Local administrators are responsible for ensuring the well-being of citizens, which includes ensuring that agricultural practices in their area comply with regulations and do not have a negative impact on the environment. In addition, local administrators are directly affected by the preferential vote of their constituents in a generally short period of time, therefore they need to demonstrate/proclaim a clear commitment and alignment in favour of the life quality of their constituents on issues related to the specific territory, and at the same time, they should not displease specific economic groups and interests. Therefore, they are expected to be interested in the criteria of air quality and water quality and also consider the cost of implementing new technologies, as companies and farmers are constituents as well. A study

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by Lovell et al. (2010) found that local administrators are more likely to support policies that promote sustainable agricultural practices if they are perceived to be cost-effective.

Companies/technology providers, service providers: Companies/technology providers and service providers are essential stakeholders as they play a vital role in developing and providing technologies and services to manage nutrients and slurry in agriculture and have a direct interest in developing and promoting technologies that can improve nutrient and slurry management in agriculture. Therefore, they are expected to be interested in the criteria of energy demand and costs, and market openness. They may also be interested in the criteria of air quality, water quality, and climate change if these are key concerns of their customers.

Policy/decision makers at regional/supranational levels: Policy and decision-makers at regional and supranational levels have the power to develop policies and regulations to govern nutrient management in agriculture that are far-reaching, eluded by local and particular interests, and committed to the common good. Therefore, they are expected to be interested in all the criteria, including air quality, water quality, climate change, energy demand, and, of course, costs. In fact, policies that promote sustainable agriculture are more likely to be supported if they are perceived to have positive economic and social impacts. Moreover, the mediation action of policy can ensure that the costs (and benefits) of nutrient management practices are distributed equitably across different stakeholder groups, deciding who and in what share will pay for sustainability measures.

Based on the main stakeholder groups involved (farmers and citizens), the needs in society, and the results of stakeholder perceptions (results of FGs conducted on supply and demand, D5.3) three weighting options were selected to frame the solutions.

I. Environmental perspective: local impacts such as air quality and water quality are given the main weight. The environmental criterion is given globally 56% share (Table 54)
II. Environmental perspective: global impacts of GHG direct emissions and energy recovery are given the main weight- Globally the environmental criterion is given 56% share.
III. Economic perspective: indicators related to the economic criterion are given the main weight (63%). weight of each indicator for the selected weighing options

Table 54: weighting set

	W_{i1}	W_{i2}	W_{i3}	W_{i4}	W_{i5}	W_{i6}	W_{i7}	W_{i8}	W_{i9}
Environmental perspective: global impacts	5%	5%	**42%**	4%	16%	16%	4%	4%	4%
			56%					44%	

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Environmental perspective: local impacts	**25%**	**25%**	4%	3%	10%	10%	9%	9%	5%
			56%					44%	
Economic perspective	9%	9%	9%	9%	6%	6%	**25%**	**25%**	1%
			37%					67%	

W_{i1} Air quality
W_{i2} Water quality (NP)
W_{i3} GHG
W_{i4} Soil quality
W_{i5} Energy recovery
W_{i6} Energy demand
W_{i7} Capex
W_{i8} Opex
W_{i9} Feed/ feedstock security

Calculation of indicators

The indicators were calculated for each solution and for the baseline of each solution. The final values reported for each indicator (numerically and graphically) are the difference between the two (baseline and solution), **thus the advantages or disadvantages that emerge from the application of the solution with respect to the baseline**. For each indicator, equal values in baseline and solution (difference=0) means that there is no advantage or disadvantage in applying the solution relative to that indicator.

N import by feed (t N ha^{-1}): This indicator quantifies the extent of the reduction of nitrogen import by feed coming from extra livestock areas (i.e. import of N from oversea soy). It is an indicator that evaluates the effectiveness of strategies that reduce the import of feed in areas with high livestock intensity. It is calculated as tons of nitrogen for each hectare of land in which the solution is applied. The reference to the ha of land is straightforward in the case that feed is cultivated as a second crop on a surface. In the case of slurry used to grow insects or other feeds (duckweed, microalgae), the link is to the amount of slurry that would have been used on 1 ha of land and opposite is used to produce the insects or the algae.

Direct ammonia emissions (kgN-NH_3 ha^{-1}): Ammonia emitted in baseline and solution. The emission is related to the land surface and to the nutrients applied (in baseline and solution). Emissions from storage or treatment devices (i.e. nitrification and denitrification tank), are also accounted for and linked to the amount of emissions caused by the material (slurry/by-products) that is applied to 1 ha of land (or removed as in surplus from 1 ha of land).

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Nitrogen leaching (kg N-NO_3 ha^{-1}): nitrogen lost to waterbodies. The value is calculated based on the nitrogen applied and the amount lost in 1 ha of surface (in baseline and solution).

P (over) application (kg P ha^{-1}): the indicator highlights if overapplication of P occurs in baseline or solution. For the solution dealing with P recovery, the calculation in baseline and solution, is based on a "standard "fertilization plan" and the amount of P used per ha becomes the reference unit for calculating the other activity data in baseline and solution.

Soil quality (kg C ha^{-1}): The indicator is calculated as the amount of organic carbon applied per ha in the baseline situation and when the solution is applied.

Direct GHG (kgCO_2 eq ha^{-1}): GHG (methane, N_2O) emitted in baseline and solution in 1 ha of land. Emissions from storage or treatment are accounted for and linked to the amount of nutrients (slurry/by-products) that is applied in 1 ha of land (or removed from 1 ha of land). Emissions from storage or treatment devices (i.e. nitrification and denitrification tank), are also accounted for and linked to the amount of emissions caused by the material (slurry/by products) that is applied to 1 ha of land (or removed as in surplus from 1 ha of land).

Energy demand and recovery (MJ ha^{-1}): The indicator is calculated as the primary energy needed in baseline and solution. As the output must highlight differences respect to the baseline, in the calculation are included all the operations that differ in the two scenarios (all the operations and energy demand that are not affected by the application of the solution are not included). Electricity demand is calculated as primary energy considering the average electricity efficiency (Taylor et al., 2008) and electricity source in EU (EUROSTAT). In the case of solution dealing with anaerobic digestion, all the amounts are calculated on the base of the amount of digestate managed in 1 ha of land according to a standard fertilization plan.

The reason for keeping energy demand as a specific indicator in the economy criterion is that energy demand is a tangible physical factor that can be measured and compared across different nutrient and slurry management practices, not dependent on market fluctuation (as opposite the cost of energy) or market niche. Energy, of course, determines the operational cost of a solution and its viability, but the mere demand of energy can give an insight into the feasibility and applicability of the technology in future scenarios, where energy source and costs might be completely different, hence, the mere demand is an important indicator of efficiency.

Costs CAPEX and OPEX (€ha^{-1}): capex are referred to the surface of land, meaning that the calculation is made considering the management of nutrients (amount of slurry or by-products, or fertilizers) needed for 1 ha of land to grow a crop (according to a standard fertilization plan). Thus, the capital costs are divided for the lifespan of the device (years), the amount of materials processed in one year and multiplied for the amount of the material that is managed (or should be removed) from 1 ha of land. In the OPEX items are also included possible revenues that decrease the cost of the solution and

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may contribute to making the economic outcome more favourable for the solution respect to the baseline.

Baseline

Each solution is compared with its own baseline, as described in the paragraph on the calculation of the indicators. To allow general and synthetic conclusions the baselines were, when possible, harmonised, and calculated in a similar way (for example, in the solutions relating to areas with a nitrogen surplus, the surplus of nitrogen per hectare was always considered 170 kg ha^{-1}, for the sole purpose of having common calculation bases). Sometimes, however, the baseline to which the solution refers is unique, and in calculating the indicator, it must be remembered that the baseline is fundamental, as the advantages/disadvantages calculated for the solution depend also on the baseline. The objective of the analysis is to verify the improvement (or deterioration) with respect to the current factual situation.

Five types of baselines (Figure 25) can be identified, four based in nutrient-rich areas, and one based in nutrient-poor areas. In reality, the situations described by the baselines often coexist all together in the nutrient-rich zones but depending on the strategy used to close the CNP cycle, the calculation of the difference between the baseline and the scenario is done by focusing on one aspect (feed import, nutrient export etc).

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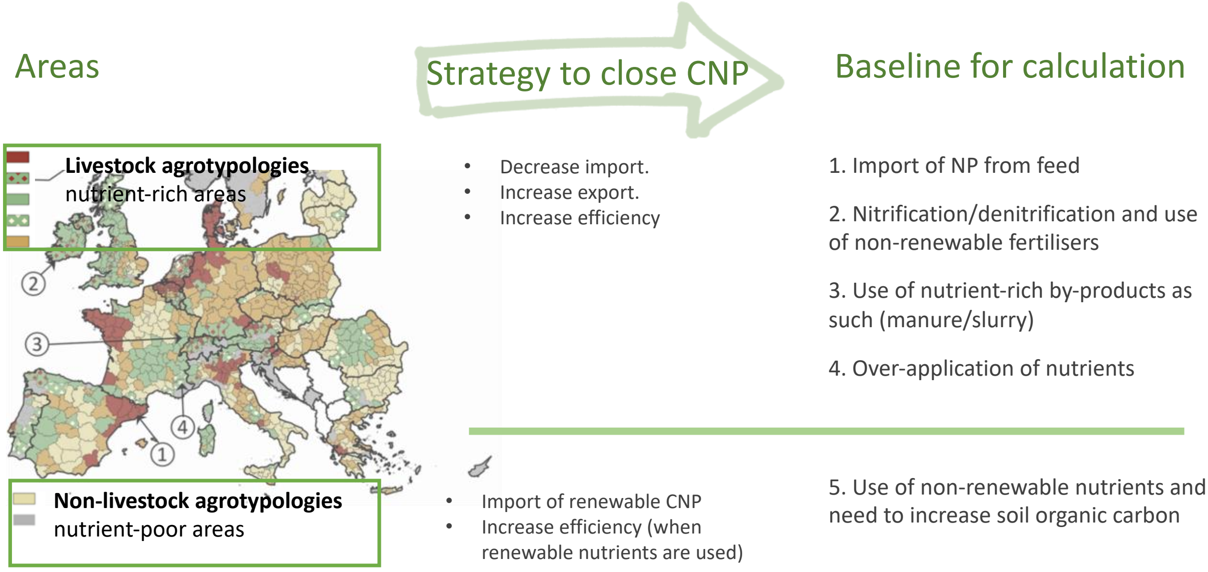

Figure 25. Areas, strategy to close CNP and baseline against which the score of indicators is calculated

The following tables show the solutions aggregated per baseline type, reporting the solutions identification number (LL number) and the detailed specification of the baseline on which the differential score of the solution is actually calculated (more information on baseline context for each solution is provided in D3.1).

baseline 1: Import of NP from feed

LL n	Solution title	Baseline description
25	Soybeans in Poland - innovative solutions in the cultivation, plant protection and feeding on farms	Soy is imported
45	INPULSE: Innovating towards the use of Spanish legumes in animal feed	Soy is imported
41	Floating wetland plants grown on liquid agro-residues as a new source of proteins	Baseline: slurry is denitrified and protein feed imported Solution: duckweed are grown on slurry to produce feed
41B	Algae grown on nutrient rich liquid agro-effluents as a new source of proteins	Baseline: slurry is denitrified and protein feed imported Solution: microalgae are grown on slurry to produce feed

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Baseline 2: Nitrification/denitrification and use of non-renewable fertilisers

LL n	Solution title	Baseline description
1	Ammonium stripping / scrubbing and NH_4NO_3 as substitute for synthetic N fertilizers	Baseline: Pig slurry is denitrified, and mineral fertilizer is used.
2	Ammonium stripping / scrubbing and NH_4SO_4 as substitute for synthetic N fertilizers	Baseline: Pig slurry is denitrified, and mineral fertilizer is used.
6	Concentrate from vacuum evaporation/ stripping as nutrient-rich organic fertilizer	Baseline: Pig slurry is denitrified, and mineral fertilizer is used.
9	Liquid fraction of digestate as a substitute for mineral N & K fertilizer	Baseline: slurry is denitrified, and mineral fertilizer is used.
20	Low temperature ammonium-stripping using vacuum	Baseline: slurry is denitrified, and mineral fertilizer is used.
23	Pig manure refinery into mineral fertilisers using a combination of techniques applicable at industrial pig farms	Baseline: NVZ, thus part of the slurry must be denitrified, and chemical N is used.
43	Pig manure evaporation plant	Baseline: Pig slurry is denitrified, and mineral fertilizer is used.
Nitrification/denitrification and import of feed		
41	Floating wetland plants grown on liquid agro-residues as a new source of proteins	Baseline: slurry is denitrified and protein feed imported Solution: duckweed are grown on slurry to produce feed
41B	Algae grown on nutrient rich liquid agro-effluents as a new source of proteins	Baseline: slurry is denitrified and protein feed imported Solution: microalgae are grown on slurry to produce feed

Baseline 3: Use of nutrient rich by-products as such (manure/slurry)

LL	Solutions	Baseline description
10	Small / Farm scale anaerobic digestion of agroresidues to increase local nutrient cycling & improve nutrient use efficiency	Cow slurry is not treated and simply stored and distributed on fields
48	Recovery of energy from poultry manure and organic waste through anaerobic digestion	Baseline: poultry manure is not treated and simply stored for successive distribution in fields.
24	Adapted stable construction for separated collection of solid manure and urine in pig housing (followed by separate post-processing)	Baseline: stable collect manure and urine together, and S/L separation is performed
27	Use of an inoculate of microbiota and enzymatic pre-cursors to reduce ammonia emissions and optimize nutrient use efficiency in poultry manure	Baseline: manure is used as such

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18	Slurry acidification with industrial acids to reduce NH_3 volatilisation from animal husbandry	Baseline: slurry is used as such by open slot injection
19	Slurry bioacidification using org. waste products to reduce NH_3 volatilisation and increase fertiliser value	Baseline: slurry is used as such by open slot injection
47	Production of growing substrates for horticulture application from poultry manure, solid state digestate and biochar through composting	Baseline: poultry manure is spread on land
62	Blending of raw and treated organic materials to produce organic fertilisers (NPC)	Baseline: raw materials (treated and untreated manure) and mineral fertilisers are used without blending. Solution: blending of materials to get balanced NPK ratio.

Slurry is exported and managed as such

55	Manure processing and replacing mineral fertilizers in the Achterhoek region	Baseline: NVZ, part of the slurry must be transported 250 km and chemical N is used.
40	Insect breeding as an alternative protein source on solid agro-residues (manure and plant wastes)	Baseline: slurry is exported and distributed elsewhere.

Baseline 4: Over fertilisation

LL	Solution	Baseline description
30	Precision farming coping with heterogeneous qualities of organic fertilizers in the whole chain	Baseline: No precision fertilization, farmers perform over application of nutrients
63	Precision fertilization of Maize using organic materials on (use of organic materials for fertilization of maize grown) conventional or soil conservation practice	Baseline: mineral fertilizer is partly used. Solution: slurry is used in substitution of chemical.
68	Integration of UAV/Drone and optical sensing technology into pasture systems	Baseline: slurry is used without monitoring. Solution: slurry is used, and drone monitoring is in place
73	Precision arable farming using bio-based fertilizers in potato growing	Baseline: mineral fertilizer is partly used. Solution: Liquid fraction and AS are used in substitution of chemical
28	Precision farming and optimised application: under-root application of liquid manure for maize and other row crops	baseline: non precision distribution of manure
13	Sensor technology to assess crop N status	Baseline: No precision distribution

Baseline 5: use of synthetic fertiliser

LL	Solution	Baseline description
16	Using digestate, precision agriculture and no-tillage focusing on OM stocking in an area characterize by the lack of it.	Mineral fertilizer is used.
17	Crop farmer using a variety of manure and dairy processing residues to recycle and build soil C, N, P fertility	Chemical N and P is used.

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21	Catch crops to reduce N losses in soil and increase biogas production by anaerobic co-digestion	Chemical N is used
14	Substituting mineral inputs with organic inputs in organic viticulture	Baseline: mineral fertilizer is used.
15	Closing the loops at the scale of farm : using the livestock manure to fertilize the feeding crop on agroforestry plots	Chemical fertiliser used. Solution: slurry is used on woody plots, crop beneath
57	Recovered organic materials and composts for precision fertilization of apple orchards and vineyards	Mineral fertilizer is used. Solution: slurry is used in partial substitution of NP.
66	Application of digestate in large scale orchards	Mineral fertilizer is used. Solution: digestate is used at the plantation of the orchard
P overapplication and use of mined P somewhere else		
49	Nitrogen and phosphorus recovery from pig manure via struvite crystallization and design of struvite based tailor-made fertilizers	Over fertilization of P in surplus area and use of chemical fertilizers for P fertilization somewhere else
52	Pilot-scale crystallizer for P recovery	Over fertilization of P in surplus area and use of chemical fertilizers for P fertilization somewhere else
8	Acid leaching of P from organic agro-residues in order to produce OM-rich soil enhancers and P-fertilizers	Over fertilization of P in surplus area and use of chemical fertilizers for P fertilization somewhere else

Data elaboration

Indicators and kind of variation:

For all the indicators the kind of variation can be *"more is better" or "less is better"*, meaning that a positive outcome is depicted when the first kind of indicator is high and a negative outcome is depicted when the second kind of indicator is high.

The indicators are calculated, according to the kind of variation, in order to be **presented as positive values when the solution highlights advantages compared to the baseline, while negative outcomes** (worsening of the indicator when applying the solution respect to baseline), are presented with negative values. As an example, a positive value in the indicator of ammonia means ammonia emissions decreased respect to the baseline, and a positive value in the indicator of costs means that there is a decrease in costs compared to those faced in the baseline. In Table 55 is reported the calculation applied for each indicator among solution and baseline in order to display positive outcomes as a positive value.

Table 55. type of indicator and calculation performed to present results

Index	Kind /direction
Reduction of N and P import by feed	more is better (solution -baseline)
Primary production	more is better (solution -baseline)

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Air quality (ammonia emission - Storage/processing)	less is better (baseline -solution)
Air quality (ammonia emission - field)	less is better (baseline -solution)
Water quality N (N leaching)	less is better (baseline -solution)
P (over)application	less is better (baseline -solution)
Soil and crop quality (carbon applied to soil)	more is better (solution -baseline)
GHG (direct emissions)	less is better (baseline -solution)
Energy recovery	more is better (solution -baseline)
Energy demand	less is better (baseline -solution)
Capex	less is better (baseline -solution)
Opex	less is better (baseline -solution)

Normalization: once the difference between the solution and the baseline has been calculated (considering the kind of variation) the value is normalized by dividing the value of the indicator by a "typical" reference value relating to that indicator. Table 56 explains the rationale for the choice of the normalization factor for each indicator.

Table 56. Normalisation factor used

Index	unit	standardization value	standardization rationale
Primary production	t $TSha^{-1}$	20	Yield (expressed as of total solids) for maize production in 1 ha of land
Air quality (ammonia emission - Storage/processing)	$kgN\text{-}NH_3ton^{-1}$	0.45	Average emission of ammonia from 1 m^3 of slurry in non-covered tanks
Air quality (ammonia emissions - field)	$kgN\text{-}NH_3\ ha^{-1}$	15	Average ammonia emissions for 1 ha in baselines where organic N is used, see D.1.5
Water quality N (N leaching)	kg $N\text{-}NO_3\ ha^{-1}$	63	Nitrate leaching for 1 ha in baselines where organic N is used (D.1.5)
P (over)application	kgP ha^{-1}	31	Reference limit of P application in Dutch soil.
Soil quality (carbon applied to soil)	kgC ha^{-1}	3000	Average carbon amount applied in 1 ha by cattle manure (170 kg of N/ha ceiling)

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GHG (storage or other treatment.)	kg CO_{eq} ha^{-1}	1589	N_2O emissions due to NDN for 170 kg of N
GHG (direct emissions field)	kg CO_{eq} ha^{-1}	3044	Average N_2O emissions for 1 ha in baseline (organic input) cf D.1.5
Energy recovery	MJ ha^{-1}	546	Energy content of 1 m^3 of cattle slurry in AD
Energy demand	MJ ha^{-1}	6113	Distribution of 85 m3 of slurry (to provide 170 kg N)
Costs CAPEX	€ ha^{-1}	151	equal as for opex
Costs OPEX	€ ha^{-1}	151	Average cost to manage 1 ha including : distribution of slurry up to 170 kg +purchase of 70 kg of urea
Reduction of N and P import by feed	t Nha^{-1}	0.17	Amount of animal N allowed per hectare, that support crop productivity

The purpose of data normalization is to convert the quantities with different dimensions to the same dimensionless form, to facilitate the comparison between the alternatives. The data normalization also creates an opportunity to weigh the criteria and assign priority.

Choosing to use a specific normalization value that is significant for the indicator, allows for achieving a normalization process that guarantees simplicity and manageability of the results because the reference values are intuitive and directly connected with agricultural practices. The normalized value is finally multiplied by 10, for a simple presentation of the results.

For simplicity, after normalisation, some indicators are summed and presented as one category, i.e water quality. In Table 57 are presented the summed indicators displayed in the final presentation.

Table 57. Type of indicator and calculation performed to present results

Indicator calculated	**Indicator displayed**
Air quality (ammonia emission -Storage/processing)	Air quality
Air quality (ammonia emissions - field)	
Water quality N (N leaching)	Water quality
P (over)application	
Soil quality (carbon applied to soil)	Soil quality

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GHG (storage or other treatment.)	GHG
GHG (direct emissions field)	
Energy recovery	Energy recovery
Energy demand	Energy demand
Costs capex	Total costs
Costs opex	
Primary production	Feed/feedstock security
Reduction of N and P import by feed	

Weighting: performed on the normalized indicators according to the three weighting sets proposed (Table 54).

Finale score: Simple Additive Weighting (SAW) is used to get the final score. Simple SAW is a widely used method in MCA, as it is relatively simple, and passages remain clear and transparent during data processing. It allows fast and critical identification of bias, review of criteria and changes of weighting score if they prove not to be suitable for the purpose set for the investigation. In SAW the overall score is calculated as the weighted sum of the standardized scores (Janssen, 1992). More specifically, in SAW the weights are assigned to each criterion, representing the relative importance of each criterion in the decision-making process. Then, each alternative is evaluated based on its performance on each criterion, and the weighted criteria are summed to arrive at a final evaluation or clustering. As SAW is methodologically sound, easy to explain and transparent, this method is recommended in the MCA manual published by the Dutch Commission for EIA (Bonte et al., 1997).

Final score: after normalisation and weighting the indicators are summed and stacked for graphical presentation. Each "stack" represented in the graphs briefly describes the areas for improvement and deterioration of the solution with respect to its baseline.

Data source

The data used for the calculation of indicators come from the collection of primary data performed during the investigation of solutions and collected in D.2.6.

Further data come from D3.4, namely the inventory of the LCAs of the solutions that were submitted to this investigation, and from D3.3, CBA, where more detailed economic data were collected and critically discussed. Missing data and data gaps, where they occurred, were filled by literature data

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and proxy data, able to highlight the critical points the solutions were addressing. In Table 58 are indicated the data source for the calculation of the indicator of each solution.

Table 58. Data source used for the calculation of indicators

	Long-list Abstract Title	D2.6	DEMO DATA	D3.4	D.3.3	D.3.1 and literature validation
10	Small / Farm scale anaerobic digestion of agroresidues to increase local nutrient cycling & improve nutrient use efficiency					
48	Recovery of energy from poultry manure and organic waste through anaerobic digestion					
61	Tailor made digestate products (tool development)					
8	Acid leaching of P from organic agro-residues in order to produce OM-rich soil enhancers and P-fertilizers					
11	Recycling fibres of manure as organic bedding material for dairy cows					
24	Adapted stable construction for separated collection of solid manure and urine in pig housing (followed by separate post-processing)					
27	Use of an inoculate of microbiota and enzymatic pre-cursors to reduce ammonia emissions and optimize nutrient use efficiency in poultry manure					
18	Slurry acidification with industrial acids to reduce NH3 volatilisation from animal husbandry					
19	Slurry bioacidification using org. waste products to reduce NH3 volatilisation and increase fertiliser value					
16	Using digestate, precision agriculture and no-tillage focusing on OM stocking in an area characterize by the lack of it.					
17	Crop farmer using a variety of manure and dairy processing residues to recycle and build soil C, N, P fertility					
71	Practices for increasing soil organic matter content in Dutch soils					
21	Catch crops to reduce N losses in soil and increase biogas production by anaerobic co-digestion					
30	Precision farming coping with heterogeneous qualities of organic fertilizers in the whole chain					
28	Precision farming and optimised application: unter-root application of liquid manure for maize and other row crops					
63	Precision fertilization of Maize using organic materials on conventional or soil conservation practice					
73	Precision arable farming using bio-based fertilizers in potato growing					
68	Integration of UAV/Drone and optical sensing technology into pasture systems					
13	Sensor technology to assess crop N status					
14	Substituting mineral inputs with organic inputs in organic viticulture					
15	Closing the loops at the scale of farm : using the livestock manure to fertilize the feeding crop on agroforestry plots					
57	Recovered organic materials and composts for precision fertilization of apple orchards and vineyards					
66	Application of digestate in large scale orchards					
1	Ammonium stripping / scrubbing and NH4NO3 as substitute for synthetic N fertilizers					
2	Ammonium stripping / scrubbing and NH4SO4 as substitute for synthetic N fertilizers					
6	Concentrate from vacuum evaporation/ stripping as nutrient-rich organic fertilizer					
9	Liquid fraction of digestate as a substitute for mineral N & K fertilizer					
47	Production of growing substrates for horticulture application from poultry manure, solid state digestate and biochar through composting					
62	Blending of raw and treated organic materials to produce organic fertilisers (NPC)					
49	Nitrogen and phosphorus recovery from pig manure via struvite crystallization and design of struvite based tailor-made fertilizers					
52	Pilot-scale crystallizer for P recovery					
65	Struvite as a substitute of synthetic P fertilizer					
20	Low temperature ammonium-stripping using vacuum					
23	Pig manure refinery into mineral fertilisers using a combination of techniques applicable at industrial pig farms					
43	Pig manure evaporation plant					
55	Manure processing and replacing mineral fertilizers in the Achterhoek region					
22	BIO-PHOSPHATE: high temperature reductive thermal process recovery of concentrated Phosphorus from animal bones					
40	Insect breeding as an alternative protein source on solid agro-residues (manure and plant wastes)					
25	Soybeans in Poland - innovative solutions in the cultivation, plant protection and feeding on farms					
45	INPULSE: Innovating towards the use of Spanish legumes in animal feed					
34	Secondary harvest: additional valorisation of crop harvest and processing residues					
41	Floating wetland plants grown on liquid agro-residues as a new source of proteins					
41B	Algae grown on nutrient rich liquid agro-effluents as a new source of proteins					

16.Results and discussion

Nutrient-rich areas: economic perspective and clustering

As first, solutions suitable for, and applicable to "nutrient-rich areas" are investigated, and the set of strategies that the solutions implement are: nutrient export, prevention of import and increase in

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efficiency. For this group of technologies, a first simple calculation of the score, starting from the Farmer's perspective (Economic weighting set), highlights that many of the solutions applied allow a cost-saving respect to a non-circular baseline.

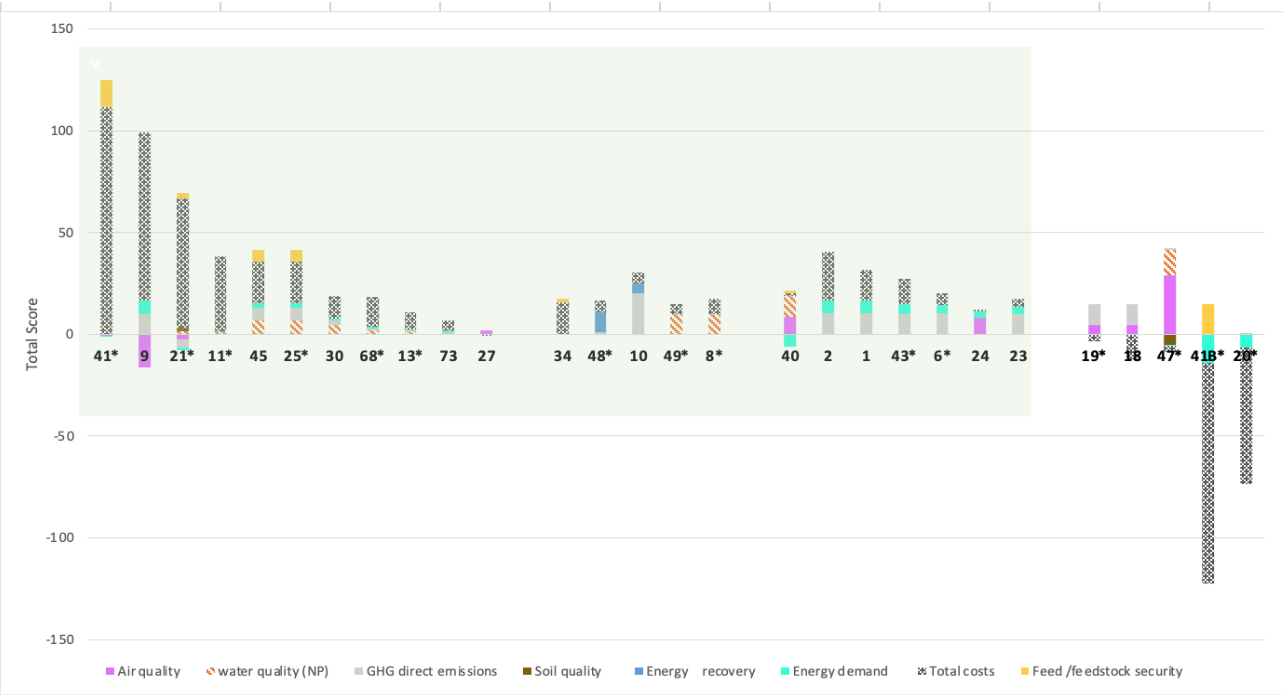

Figure 26. Total score of solutions suitable for nutrient-rich areas, calculated according to the "Economic perspective" weighting.

Costs with positive values indicate a saving respect to baseline. Solutions marked with an asterisk * were investigated at TRL of 6 or less.

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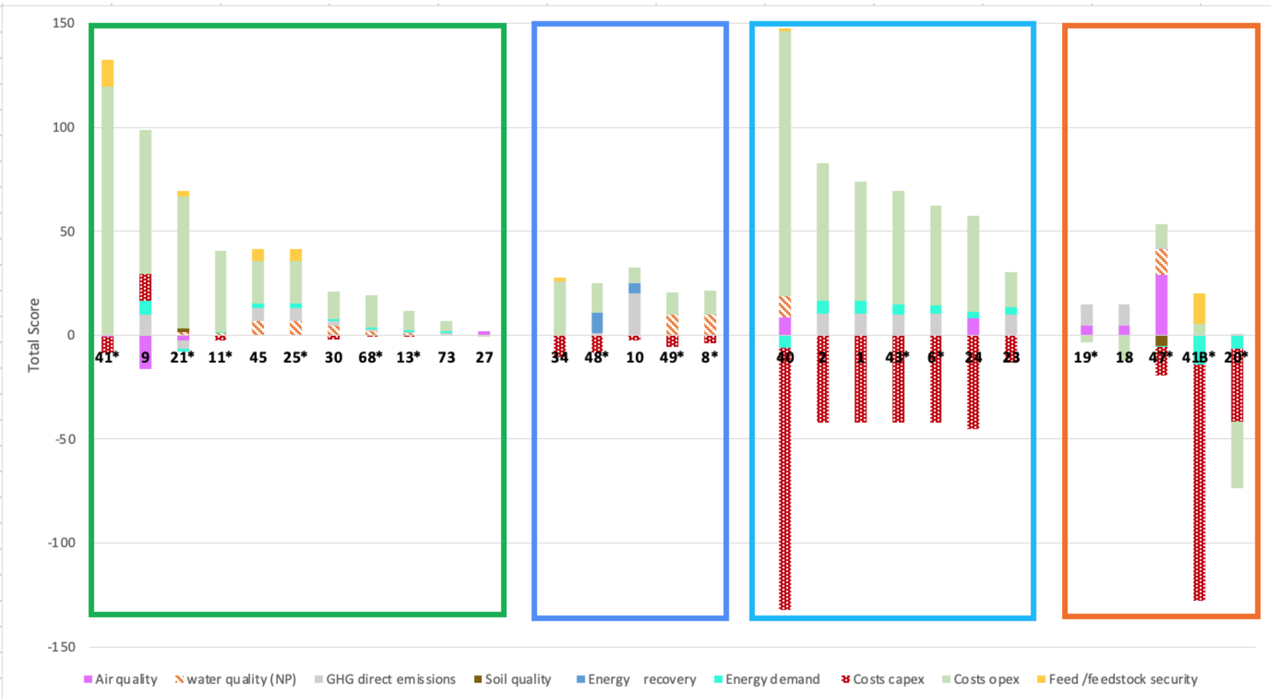

Figure 27. Total score of solutions according to the weighting set: "Economic perspective". Costs (difference respect to baseline) have been reported as separate CAPEX and OPEX. Four clusters are identified.

Considering also the financial risk, meaning the capital costs to be invested initially to implement the solution, the analysis allows to divide the solutions into four main clusters. In Figure 27 the difference values of operating costs and investment costs of each solution with respect to the baseline are shown with distinct colours.

The first cluster **"easy and ready"** includes solutions that are in themselves economically advantageous (if well managed) with respect to the baseline, due both to increased efficiency and savings. CAPEX does not exceed 10% of the savings/earnings (positive economic difference) that can be achieved thanks to the solution. These solutions are easy and straightforward, can be applied widely and all have a reported Likert scale of applicability above 7 out of 10, together with affordable or negligible investment costs.

Table 59. Complete name of the solutions in cluster I

n	Solution name
41	Floating wetland plants grown on liquid agro-residues as a new source of proteins
9	Liquid fraction of digestate as a substitute for mineral N & K fertilizer
21	Catch crops to reduce N losses in soil and increase biogas production by anaerobic co-digestion

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11	Recycling fibres of manure as organic bedding material for dairy cows
45	INPULSE: Innovating towards the use of Spanish legumes in animal feed
25	Soybeans in Poland - innovative solutions in the cultivation, plant protection and feeding on farms
30	Precision farming coping with heterogeneous qualities of organic fertilizers in the whole chain
68	Integration of UAV/Drone and optical sensing technology into pasture systems
13	Sensor technology to assess crop N status
27	Use of an inoculate of microbiota and enzymatic pre-cursors to reduce ammonia emissions and optimize nutrient use efficiency in poultry manure

The deployment of these solutions needs to be supported by information and dissemination activities **(ID)**, mainly highlighting economic savings, assessed by independent and reliable institutions (Toma et al., 2018). Further booster (i.e. solution 9, see chapter 10 related to manure processing agrotypology) can be Legislation Update **(LU).** Potentially this cluster could be applied to a large share of agricultural areas and companies related to the livestock agrotypologies (pig, cattle, and poultry).

The solutions of this cluster may easily become the future standard of agronomic practices, bringing advantages in terms of water quality, feed security and efficiency in energy use respect to their baselines. In Figure 28 are summarised the area of improvement covered by these solutions

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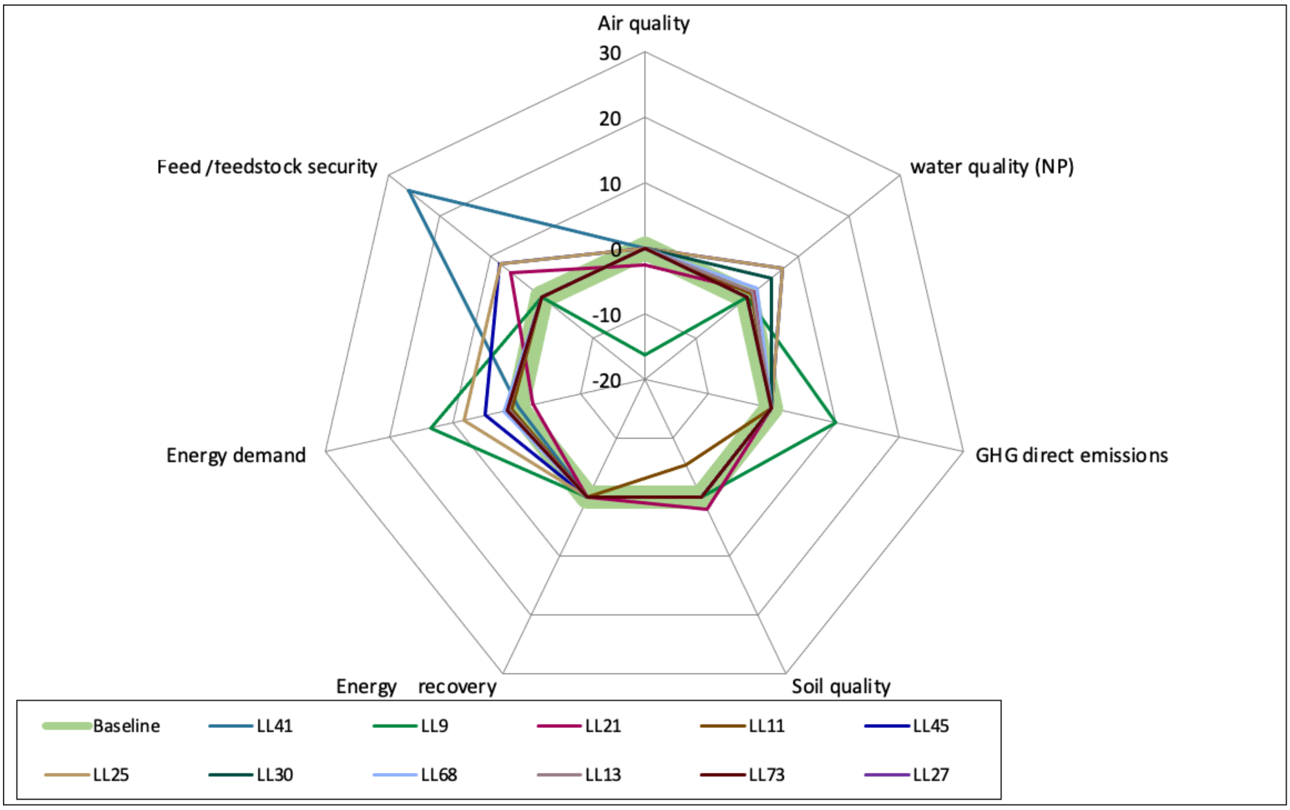

Figure 28. Area of improvement of the solution of cluster I. Green line indicates the level of baseline (no difference respect to baseline for that indicator)

The second cluster identifies solutions that are profitable (costs in solutions are lower than in baseline), require medium-high investments (CAPEX are 30% of the positive economic difference that can be achieved thanks to the solution) and are more "demanding" in terms of technical and entrepreneurial skills, thus they may benefit from information and dissemination actions, as cluster I, and also require accompanying measures, such as technical support, guidance to access finance and credits, and platforms to aggregate initiative.

For all the solution an effort is necessary for the company in capacity building, as the "new tasks" differ considerably from what is the core of agricultural activity (i.e. anaerobic digestion), and in some cases, it is likely that the activity is conducted or supported by companies that are not from the agricultural sector (LL 49 and 8).

Table 60. Complete name of the solutions in cluster II

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n	Solution name
10	Small / Farm scale anaerobic digestion of agroresidues to increase local nutrient cycling & improve nutrient use efficiency
48	Recovery of energy from poultry manure and organic waste through anaerobic digestion
34	Secondary harvest: additional valorisation of crop harvest and processing residues at district level
49	Nitrogen and phosphorus recovery from pig manure via struvite crystallization and design of struvite based tailor-made fertilizers
8	Acid leaching of P from organic agro-residues in order to produce OM-rich soil enhancers and P-fertilizers

In Figure 29 are summarised the areas of improvement of solutions in cluster II.

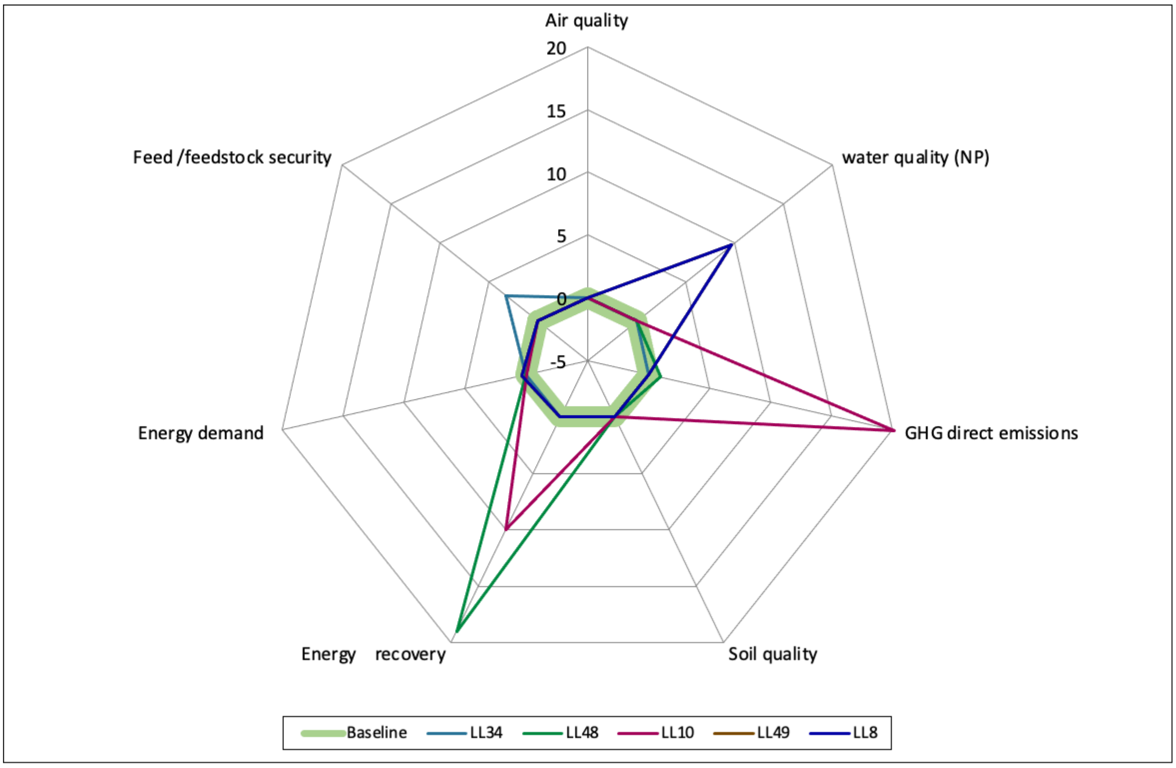

Figure 29. Area of improvement of the solution of cluster II. Green line is the level of baseline (no difference respect to baseline for that indicator)

The third cluster gathers solutions that might be economically advantageous compared to the baseline (considering in the baseline the legal environmental constraints of the nitrates directive and the current practices such as NDN) but involve a significant initial investment. Besides, some of the

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solutions are profitable in niche markets, sometimes immature and unpredictable, and therefore are perceived as financially risky. These solutions by sure demand high organisational, technical, and entrepreneurial skills. Specific barriers exist for solutions in this cluster, i.e. solutions involving the production of ammonium fertilisers from manure would be profitable if legislation updates -allowing the use as mineral fertiliser - unlocked the market potential.

For this group of solutions to be applied, it is essential to de-risk investments, support aggregation, put in place facilitation of access to finance and credits (Louman et al., 2020), and provide technical support for the entrepreneurial process: i.e. elaboration of feasibility plans and business plans with experts, discussion groups with other entrepreneurs, technical training (Kuehne et al., 2017; Stræte et al., 2022). Finally, also support for reaching and navigating the market (common market platforms) could help (Stræte et al., 2022). Supportive measures, other than economic incentives, have already proved to address the financial and technical barriers that often prevent companies from adopting sustainable practices (Masi et al., 2022).

Table 61. Complete name of the solutions in cluster III

n	Solution name
2	Ammonium stripping / scrubbing and NH4SO4 as substitute for synthetic N fertilizers
1	Ammonium stripping / scrubbing and NH4NO3 as substitute for synthetic N fertilizers
43	Pig manure evaporation plant
23	Pig manure refinery into mineral fertilisers using a combination of techniques applicable at industrial pig farms
40	Insect breeding as an alternative protein source on solid agro-residues (manure and plant wastes)
6	Concentrate from vacuum evaporation/ stripping as nutrient-rich organic fertilizer
24	Adapted stable construction for separated collection of solid manure and urine in pig housing (followed by separate post-processing)

In Figure 30 are summarised the areas of improvement of solutions in cluster III

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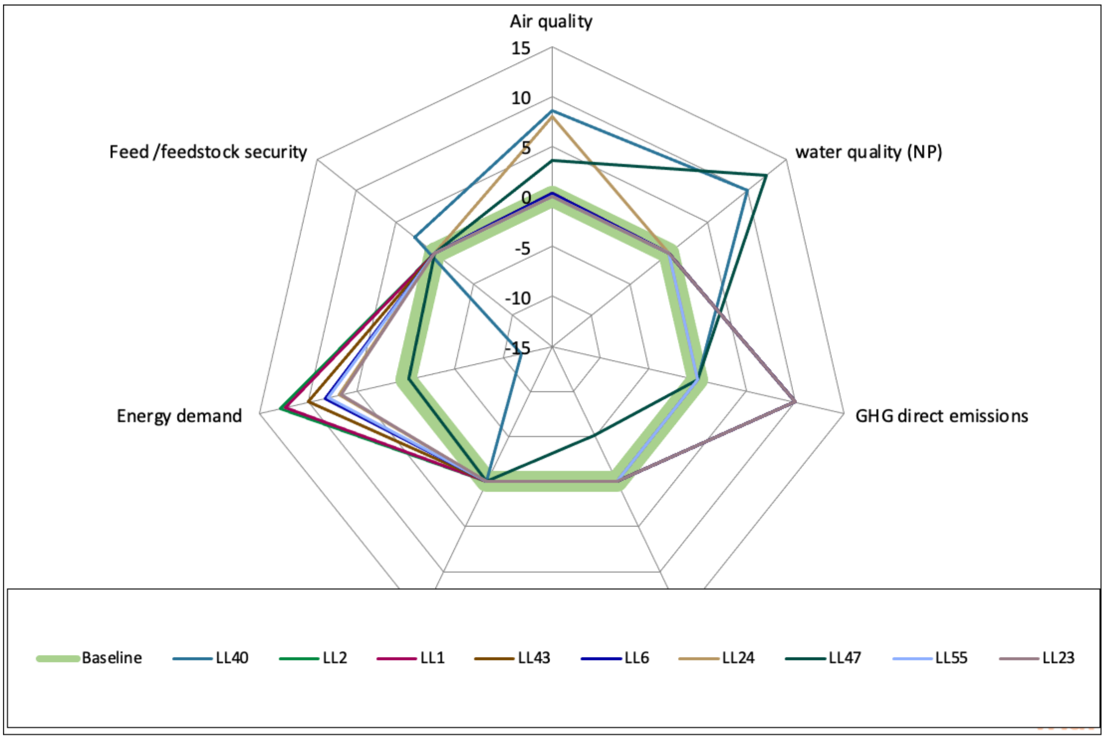

Figure 30. Area of improvement of the solution of cluster III. Green line is the level of baseline (no difference respect to baseline for that indicator)

The fourth cluster of solutions includes solutions that bring specific environmental benefits in closing the CNP cycles and are not economically attractive at present. Some of the solution (LL20 and 41b LL47) exhibit high energy demand and /or costs at pilot level, or energy balance is still not stable and may benefit from further industrial development. LL47 have economic potential due to the opportunity to enter niche markets (i.e. growing substrate) whose prices are able to partially sustain the processing (LL47). In future, legislation and environmental constraints may determine the need for farmers to approach the treatment of poultry manure, and therefore the willingness to contribute part of the costs and make the initiative sustainable and profitable. Still the market's capacity to receive the processed material is limited to niches. For the other solutions that are technologically mature (TRL 9) the drivers are specific economic support or legislative constraints (as seen in the specific barriers and booster section of the pig agrotypology, LL 18 and 19).

Table 62. Complete name of the solutions in cluster IV

n	Solution name
19*	Slurry bioacidification using org. waste products to reduce NH3 volatilisation and increase fertiliser value

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18	Slurry acidification with industrial acids to reduce NH_3 volatilisation from animal husbandry
47*	Production of growing substrates for horticulture application from poultry manure, solid state digestate and biochar through composting
55	Manure processing and replacing mineral fertilizers (in the Achterhoek region)
41B*	Algae grown on nutrient rich liquid agro-effluents as a new source of proteins

In Figure 31 are summarised the areas of improvement of solutions in cluster IV.

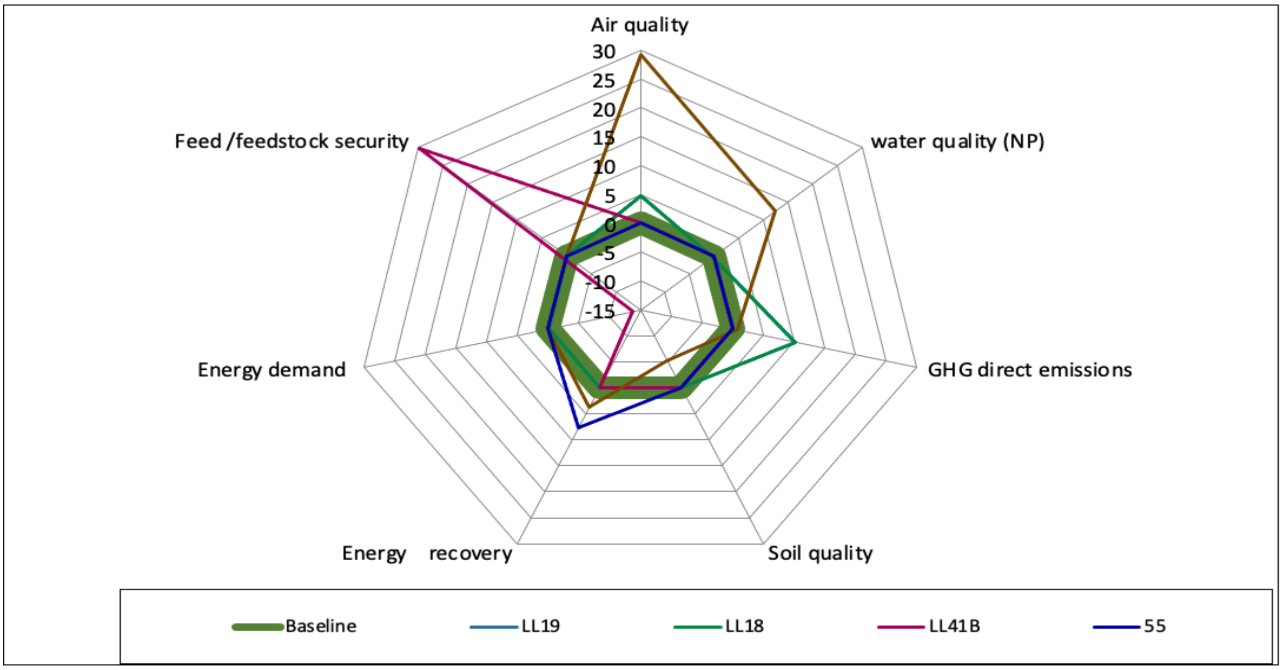

Figure 31. Area of improvement of the solution of cluster III. Green line is the level of baseline (no difference respect to baseline for that indicator)

In Table 63 is presented a resume of solutions, economic clusters, and potential applicability of solutions within the agrotypologies in EU, and thus the share of the UAA in Europe that could be affected.

Table 63. Solutions, type of supports needed and potential share of applicability in EU UAA

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Cluster	LLn	Pig (5% UAA)	Poultry (5% UAA)	Cattle arable (24% UAA)	Crop other than feed (28% UAA)	Vegetable (3% UAA)	Permanent crop orchard-(3% UAA)	Permanent grassland (32% UAA)
I	41							
	9							
	21							
	11							
	45							
	25							
	30							
	68							
	13							
	27							
II	34							
	48							
	10							
	49							
	8							
III	40							
	2							
	1							
	43							
	6							
	24							
	23							
IV	47							
	55							
	19							
	18							
	20							

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	41B							
	Potentially applicable							
	Partly applicable							

Nutrient-rich areas: citizens and consumers. Local impact perspective

Following the citizen perspective and attention to local impacts, it is possible to highlight the solutions that are able to close the CNP optimizing the effect on the local environment (Local impact weighting set). Figure 32 identifies solutions having an effect on local impacts (within the green box), and solutions with no improvement on local impacts, but acting on other indicators (GHG emissions energy savings, feed security).

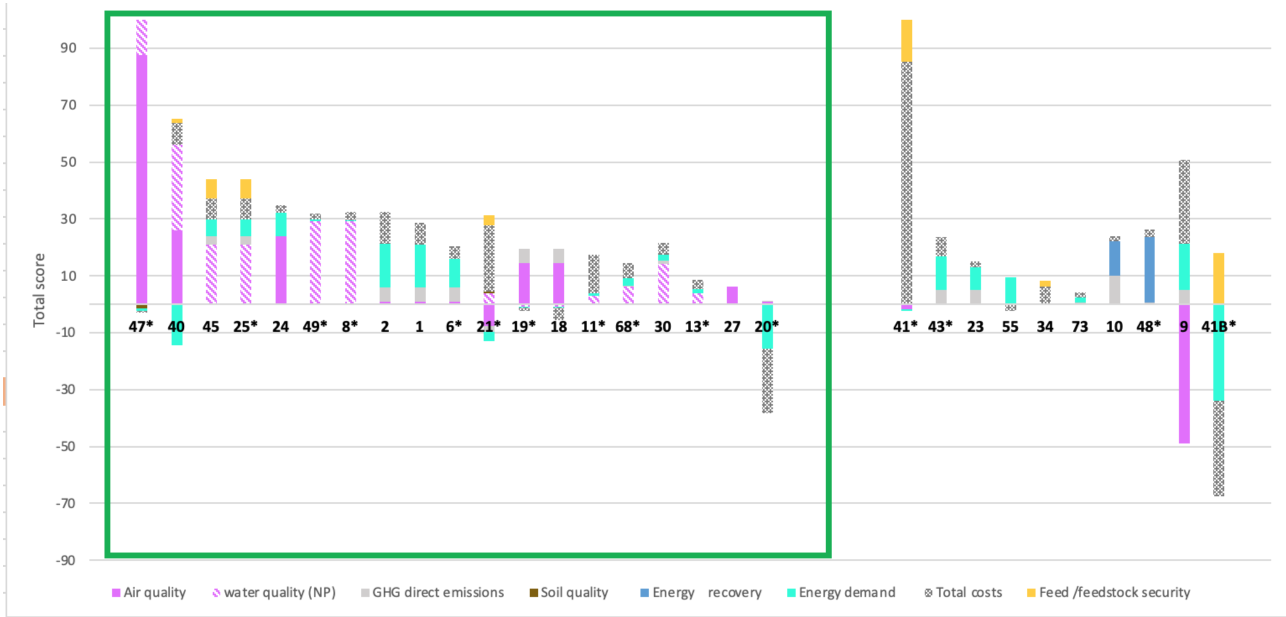

Figure 32. Solutions able to close the CNP optimizing the effect on the local environment (water and air quality)

The solutions within the green box are specifically relevant in areas with local nutrient problems, such as critical air pollution (Catalonia, Po Valley, north-western Europe) and water eutrophication (North Sea, north Europe).

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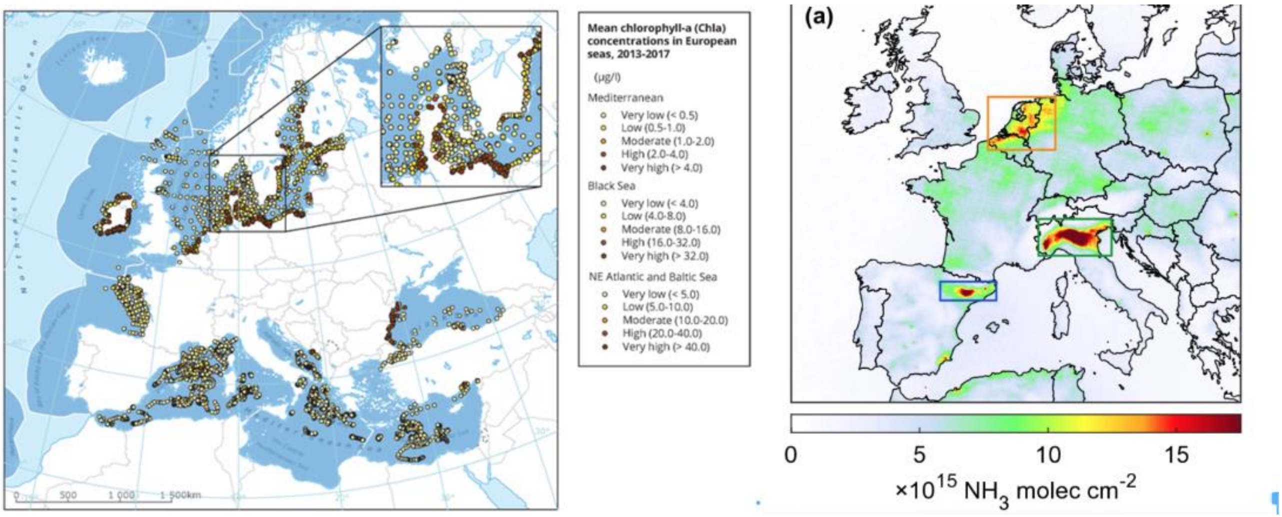

Figure 33. Chlorophyll-a concentrations in European seas (EEA) and ammonia concentration in air over EU (Van Damme, 2022)

Nutrient rich areas: Global impact perspective

In Figure 34 are highlighted solutions that are able to close the CNP optimising the effect on the global impacts, i.e. mainly on GHG emissions (global impact weighting set). Solutions show a positive effect on the GHG emissions, some reducing the direct emissions of GHG, others reducing energy consumption compared to the baseline situation.

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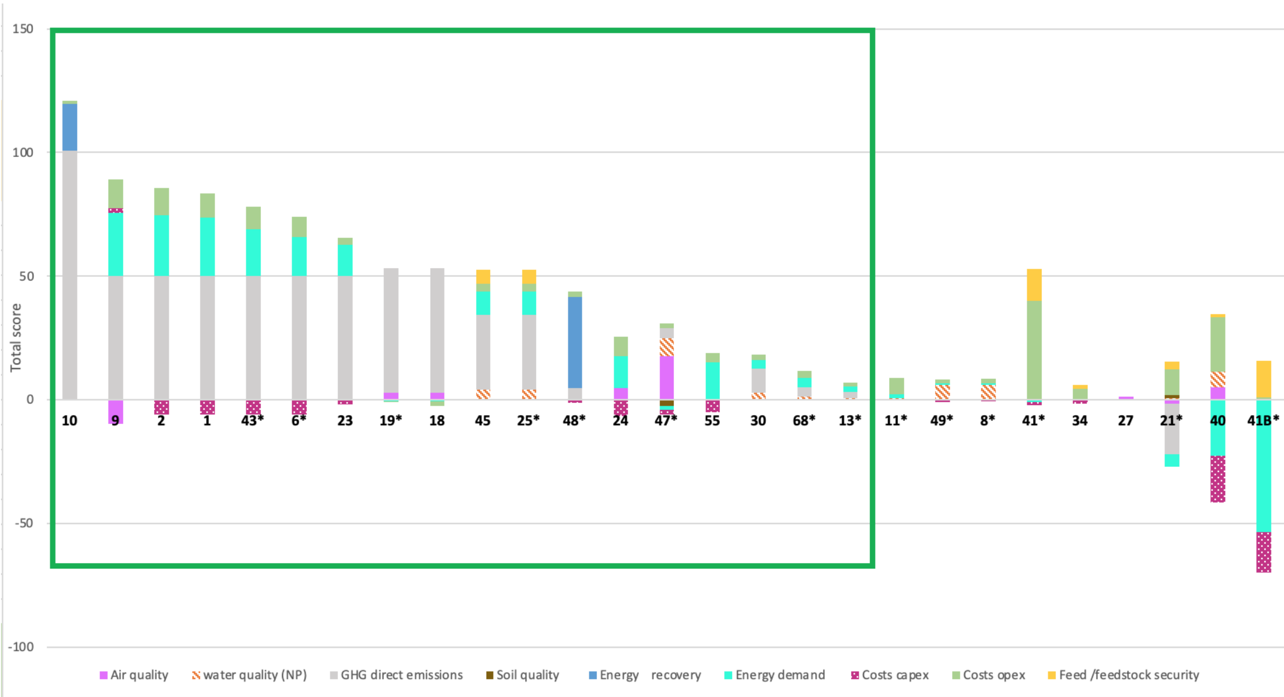

Figure 34. Solutions able to close the CNP optimizing global impacts (GHG direct emissions and energy consumption)

In Table 64 is presented a graphical resume of solutions, economic clusters (i.e. support needed), potential applicability as share of the total UAA in EU and effects on the environment.

Table 64. Solutions, applicability, and main effect on environment

	Type of support	Potential applicability (% UAA)	Effect on local impact	Effect on global impact
41		5%		
9		63%		
21		65%		
11	I	24%		
45		2%		
25		2%		
30		60%		
68		32%		
13		68%		
27		5%		
34		63%		
48	II	5%		
10		35%		
49		5%		
8		35%		
40		MC		
2		68%		

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1		68%		
43	III	68%		
6		63%		
24		0.4%		
23		68%		
47		MC		
55		35%		
19		5%		
18	IV	5%		
20		TRL		
41B		TRL		

MC: market constraints for large implementation, TRL: TRL to be increased

Nutrient-poor areas

Solutions suitable for and applicable to "nutrient-poor areas" basically use two strategies for closing the CNP cycle: to import nutrients from different areas or production chains (i.e slurry but also by-products and waste) and to increase the nutrient use efficiency.

As for the nutrient surplus areas, a first analysis is performed using the economic perspective weighting set, to highlight the economic feature or needs of the implementation.

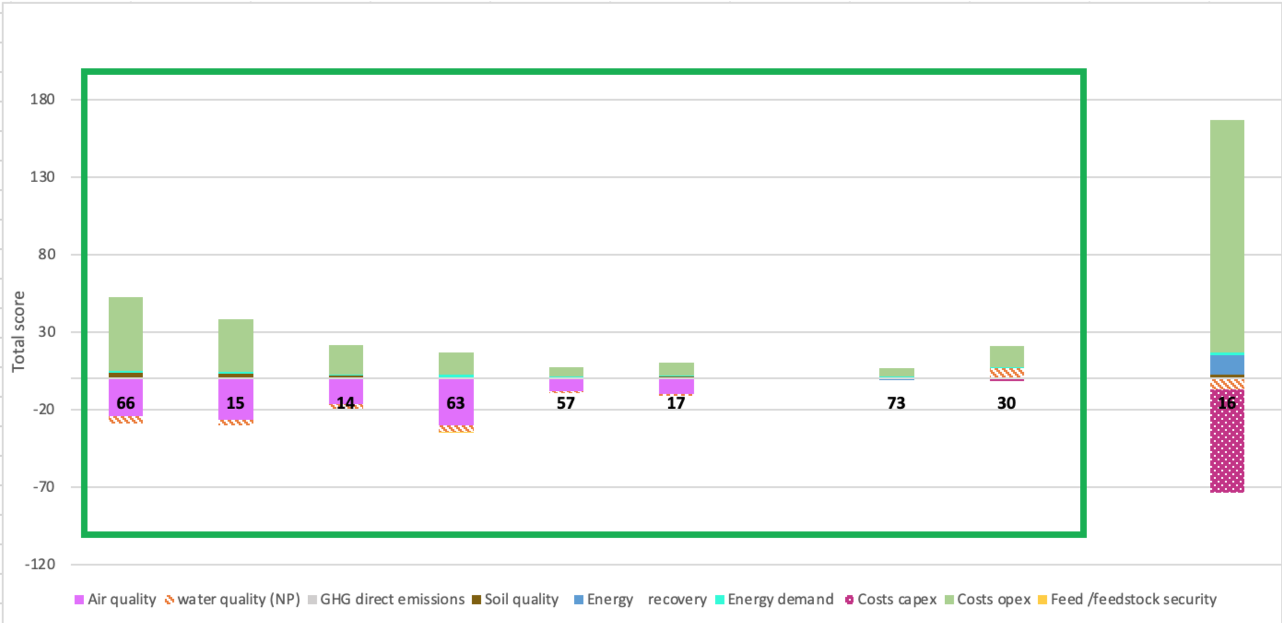

Figure 35. Calculation of the total score of solutions for nutrient poor areas. Weighting set: Economic perspective.

Table 65. Complete name of the solutions for nutrient poor areas

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n	Solution name
66	Application of digestate in large scale orchards
15	Closing the loops at the scale of farm : using the livestock manure to fertilize the feeding crop on agroforestry plots
14	Substituting mineral inputs with organic inputs in organic viticulture
63	Precision fertilization of Maize using organic materials on (use of organic materials for fertilization of maize grown) conventional or soil conservation practice
57	Recovered organic materials and composts for precision fertilization of apple orchards and vineyards
17	Crop farmer using a variety of manure and dairy processing residues to recycle and build soil C, N, P fertility
73	Precision arable farming using bio-based fertilizers in potato growing
30	Precision farming coping with heterogeneous qualities of organic fertilizers in the whole chain
16	Using digestate, precision agriculture and no-tillage focusing on OM stocking in an area characterize by the lack of it.

Not surprisingly, all the solutions are economically favourable, even more in the current contextual situation of high energy and fertiliser costs (March 2023). In fact, the solutions replace chemical fertilisers with recovered ones, and the savings in money and energy are proportional to the amount of fertiliser used (replaced) for surface unit. An average distance of 50 km for solid manure is well suited to the economic balance. These solutions are generally low-cost and ready to be used by farmers, with affordable technology involved in distribution. All solutions score 7-9 in terms of applicability. One solution (LL16 on the right-hand side of the figure) involves a more complex cycle closure, as it recovers nutrients from sewage sludge, thus implying not only higher income but also higher investment costs, as well as higher entrepreneurial, technical, and organisational skills. The positive effect of these solutions is mainly on global impacts due to the saving of energy with respect to baseline.

On the other hand, also in the economic weighting set, is already visible that some impacts worsen respect to the baseline due to the higher local emissions. In Figure 36 are reported the results considering local and global impact weighting.

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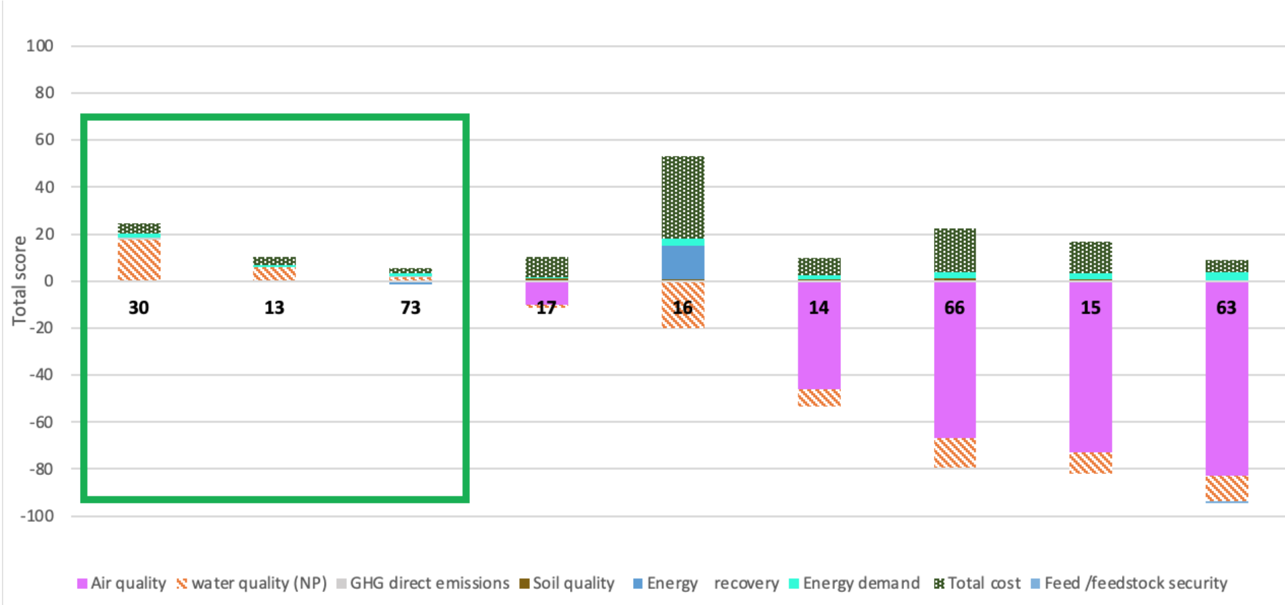

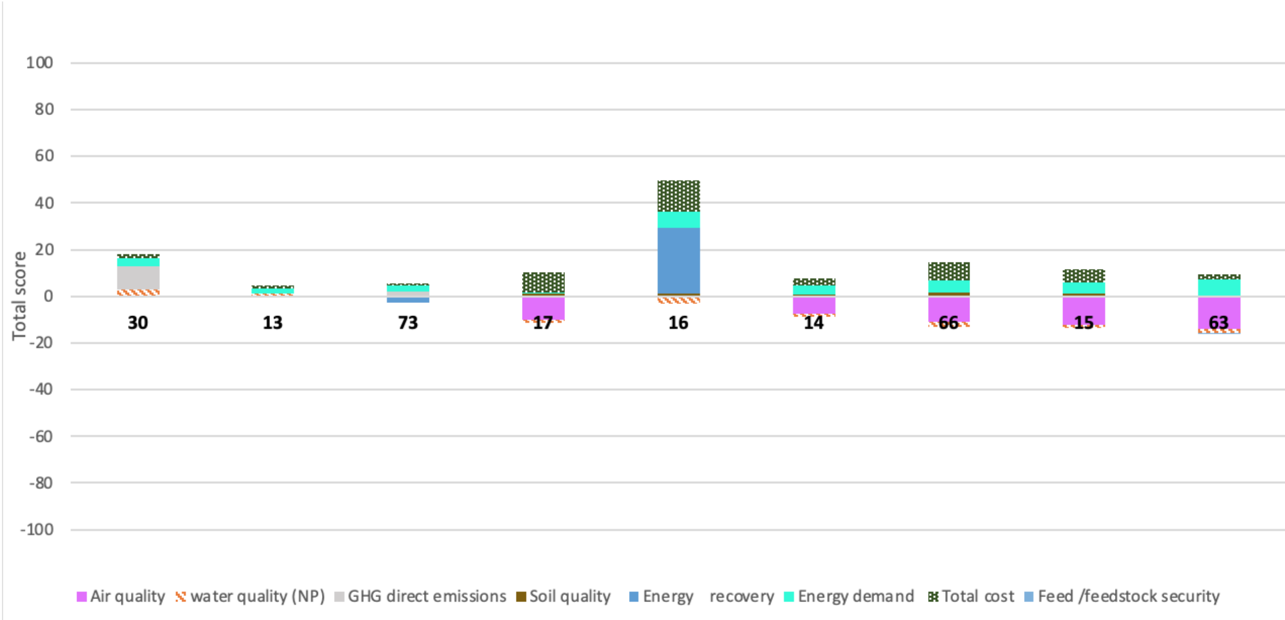

Figure 36. Calculation of the total score of solutions for nutrient poor area. Weighting set: local (upper figure) and global impacts (lower impacts).

Solutions LL30, 13, 73 are the ones implementing the more effective measure to increase efficiency and displace the lowest emissions, thus resulting in a global improvement of local impacts respect to baseline.

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The outcomes of solutions LL30, 13, 73 highlight that the export strategy of nutrients from livestock nutrient-rich areas towards non-livestock areas must be accompanied by strategies to increase efficiency so as not to replicate the environmental issues in nutrient-rich areas.

Direct emissions results are mixed, but all the solutions achieve an improvement in the global impact perspective (as investigated) due to the saving of energy for the craft of synthetic fertilisers.

In Table 66 is reported the agrotypology to which each solution can be applicable.

Table 66. Solutions for nutrient poor areas and agrotypology for application

N	Pig (5% UAA)	Poultry (5% UAA)	Cattle arable (24% UAA)	Crop other than feed (28% UAA)	Vegetable (3% UAA)	Permanent crop orchard-agroforestry-(3% UAA)	Permanent grassland (32% UAA)
66							
15							
14							
63							
13							
57							
73							
17							
30							
16							

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Conclusions

Agrotypologies face different problems in terms of CNP closure and need diverse strategies and solutions.

All the solutions investigated bring original models for the closure of the CNP cycles, thus allowing the saving of non-renewable primary resources (be it natural gas for the production of synthetic fertilisers or mined phosphorus).

Beyond this common characteristic inherent in circularity, the solutions for closing the CNP cycle present costs and advantages in economic and environmental terms, which have been calculated with respect to their own baselines.

In the context of the nutrient-rich regions, the solutions can be positioned, in the current average price and market conditions, according to 4 clusters: 1) economically advantageous and simple solutions; 2) advantageous solutions that require low investment and medium entrepreneurial skills; 3) advantageous solutions that require investment and high entrepreneurial skills; 4) solutions, with an interesting environmental advantage, and currently not (or not always) economically advantageous compared to baseline. The identification of these clusters allows to clearly frame which are the necessary support measures for a large implementation of solutions.

From the point of view of environmental advantages, solutions with a clear positive outcome with respect to local impacts (air and water quality) and solutions with a more marked effect on the containment of GHG emissions can be identified.

Almost half of the solutions (both with an effect on global and local impacts) belong to clusters 1 and 2, therefore with limited needs for support, and above all, the support should be aimed at disseminating technical and economic information.

Solutions with high environmental benefits but high costs or risks might require economic support or support to investment, while solutions with limited improvement but easy to implement and low cost will require information, dissemination and simplification of legislative procedures (Bazzan et al., 2022).

Table 67. Solutions and type of support for larger implementation

Solution	Support for larger implementation						
	Research	Information	technical	Legislation	quality	Aggregation/ local	Access to	Economic
17								
9								
11								
13								
21								

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22									
25									
27									
30									
41									
45									
57									
62									
63									
68									
28									
61									
8									
10									
34									
48									
49									
52									
1									
2									
6									
23									
24									
40									
43									
16									
18									
19									
20									
47									
55									
41B									

Finally, the solutions applicable in nutrient-poor areas, i.e. import of recovered nutrients from other areas to replace chemical and mined resources, are economically advantageous (allowing the saving of primary resources and costs) and implement a strategy that is specular to the export strategy in nutrient-rich areas. For those solutions is critical to combine measures that increase nutrient efficiency. Thus the combination of solutions that support the import/export strategy and increase nutrient efficiency is the pathway to effectively reach the CNP cycle closure within the agrotypology in Europe.

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