Ref. Ares(2023)8695503 - 18/12/2023

Nutri2Cycle
Nurturing the Circular Economy

Nutri2Cycle

D.3.3 CBA report comparing baseline production systems with optimized systems using innovations

Deliverable: CBA report comparing baseline production systems with optimized systems using innovations

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Quality review: Final Version
Date: 15/06/2022 (revised 18/12/2023)

Grant Agreement N°: 773682
Starting Date: 01/10/2018
Duration: 60 months
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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.

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List of Abbreviations

AAS	atomic absorption spectrophotometry
ABC	animal bone char
AD	anaerobic digestion
Al	aluminium
AN	ammonium nitrate
AS	ammonium sulphate
BBF	bio-based fertilisers
C	carbon
Ca	calcium
$Ca(OH)_2$	calcium hydroxide
CAPEX	capital expenditure
CBA	cost-benefit analysis
Cd	cadmium
CH_4	methane
COD	chemical oxygen demand
Cu	copper
d	day
DM	dry matter
EC	electrical conductivity
EC	European Commission
EU	European Union
NEW	Ex Works
FAO	Food and Agriculture Organization
Fe	iron
FRV	fertiliser replacement value
g	gram
GHG	greenhouse gases
GIS	Geographic Information System
GMC	gross margin calculation
GPS	Global Positioning System
h	hour
H2020	Horizon Europe 2020
H_2S	hydrogen sulphide
H_2SO_4	sulfuric acid
ha	hectare
IRTA	Institute of Agrifood Research and Technology
JIT	just in time
K	potassium
K_2O	potassium oxide
CAN	calcium ammonium nitrate mineral fertiliser
KCl	potassium chloride
kg	kilogram
kPa	kilopascal
L	litre
LF	liquid fraction

LL	Longlist
M	million
MAP	magnesium ammonium phosphate
Mg	magnesium
mg	milligram
MgO	magnesium oxide
MS	Member States
mS	millisiemens
N	nitrogen
N2C	Nutri-2-Cycle project
N_2O	nitrous oxide
NaOH	sodium hydroxide
Nb	niobium
NH_3	ammonia
NH_4-N	ammonium-nitrogen
NH_4NO_3	ammonium nitrate
Ni	nickel
NIR	Near-Infrared
OC	organic carbon
OFMSW	Organic Fraction of Municipal Solid Waste
OM	organic matter
OPEX	operating expense
ORP	oxidation-reduction potential
P	phosphorus
P_2O_5	phosphorus pentoxide
PAH	polycyclic aromatic hydrocarbon
Pb	lead
PV	Photovoltaics
R&D	Research & development
RDF	Recycling-derived fertiliser
REACH	Registration, Evaluation, Authorisation and Restriction of Chemicals
ROI	Return on Investment
S	sulphur
SF	solid fraction
SO_4^{3-}	sulphate ion
SOM	soil organic matter
Sr	strontium
STR	struvite
t	ton
T	temperature
Th	thorium
TN	total nitrogen
TNK	Total Nitrogen Kjeldahl
TOC	total organic carbon
TRL	Technology Readiness Level
U	uranium

UNESCO	United Nations Educational, Scientific and Cultural Organization
UREA	nitrogen fertiliser
V	vanadium
VC	variable cost
VS	Volatile solids
WP	work package
y	year
Zn	zinc

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Glossary

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.

Low temperature ammonium-stripping using vacuum: Technology that is based on the evaporation of ammonia in vacuum conditions with the aim to recover ammonia from livestock slurry and obtain an ammonia salt that can be reused as a fertiliser.

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).

Vacuum evaporation/stripping: Technology that consists of the boiling of a liquid substrate at negative pressure, at a temperature lower than the typical boiling temperature at atmospheric conditions with a purpose to optimize nutrient recovery from the waste streams and produce organic fertilizer with high content of nutrients in small volumes.

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Executive Summary

Purpose of the study

The overall aim of the NUTRI2CYCLE project is assessing novel solutions (i.e. technologies and management systems) that can support closing the current gaps in the N, P and C cycles in Europe. Assessment is done on different levels, ranging from the technical assessment (quality, quantity, etc.), over the ecological assessment up to the juridical assessment and the social impact of the proposed solutions. Within the project and based on the first findings, a priority list was drawn of those solutions that show to be the most promising solutions. Nevertheless, to assure that those prioritized solutions also actually find an entrance to the market it is important to perform an economic assessment, knowing that without an economic incentive it will be more difficult to convince stakeholders for doing the transformation to an overall circular economy.

This document is the report on the economic assessment of the solutions on the priority list. When reading the report, it is important to underline the following aspects:

- Input for doing the assessment was mainly taken from the **research done in the project** (WP1 and WP2) in combination with input from the involved sector, the market and literature study;
- The economic assessment done in this report is performed on **farm level,** more precisely even per "functional unit" in order to make things comparable – extrapolation of its outcomes to a higher regional or national level is <u>not</u> included in this report;
- The report compares the impact of a **manure intensive region** (i.e. with high nutrient pressure - Flanders) and a **manure extensive region** (i.e. with a low nutrient pressure - Croatia).
- For doing the assessment it was important to make generalizations and assumptions. The conclusions are therefore to be considered as **main indicators** rather than detailed and numeric correct tailor-made assessments.
- The CBA's for those technologies that have **defined market values** (for e.g. investments, products) are straightforward and result in **economic evaluations as payback periods and yearly balances**. On the other hand, the CBA's for those solutions that do not have defined market value yet (e.g. the biobased fertilizers) are performed by doing the "**back-calculation**" to estimate the (maximum) market value.

Major points

In total 16 technologies were analyzed at the economic level. The most important conclusions and take-home messages are:

- Where manure is to be considered a (financial) problem in the regions with high nutrient pressure (i.e. it is a cost to dispose), it generates an income in those regions that have a shortage in nutrients. For example: in Flanders disposing manure is a cost that fluctuates around 17.5 €/ton, where in Croatia manure can be considered generating an income of 10.5 €/ton in Croatia. The (economic) impact of this difference (of 28 €/ton) on economic feasibility of the N2C-solutions in very significant;
- The prices for energy (power & heat) and mineral fertilizers are determinant for the economic feasibility of most of the proposed N2C-solutions;
- Pocket digestion appears to have a very positive economic impact for piggery farms in manure extensive regions, considering the current energy costs (payback period of around 2 years);

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- The Vedows-stable system is only economically viable in the regions under nutrient pressure (i.e. manure intensive regions). In manure extensive regions there is no direct benefit from manure separation;
- With the current information it is not possible to define yet whether the use of precision farming for the application of recovered nutrients can be considered as an economically sustainable development;
- The maximal market price of recovered N-fertilizers can be 34 to 38 % higher for manure extensive regions compared to a manure intensive region without risking economic losses for the end-user;
- The maximum price for struvite can be 62 % higher in manure extensive regions;
- The cheapest method for handling biological effluent is the investment in a classic constructed wetland. The investment of a floating wetland (producing duck weed as a protein source for animal feed) is economically competitive with the solution of storage combined with disposal on land.

Recommendations

The prices of a lot of commodities have recently changed significantly. Of course, this has a major impact on the economic assessment of the researched solutions. The costs for energy, fertilizers, etc. are currently often a multiplication of the prices that were considered as normal only one year ago. At this point it is impossible to foresee how the markets and prices will evolve in the near future.

Nevertheless, the farmer will want to invest in those solutions that also provide sufficient economic security on the longer term. Therefore, it is recommended to not only update this report by the end of the project to be able to compare solutions to the expected new market situations, but also provide a framework in which the stakeholders (farmers) can do the evaluation of their case-specific situation. The latter will be addressed within the frame of the online tool that will be developed in WP2 (SRL 14).

The results of this economic assessment will also be taken into account when doing the policy recommendations (cfr. WP4) from the Nutri2Cycle project. As this study shows not only what the possible revenues on investments can be, but also what the maximal (market) price could be for the recovered nutrients it provides some background information that is very useful for policy recommendations as those results can support decisions whether an economic support (e.g. subsidy for the production of recovered nutrients) might be recommended or not.

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Introduction

NUTRI2CYCLE addresses the current gaps in the N, P and C cycles of different European agricultural systems and the related environmental problems by implementing optimized management systems whilst having a positive trade-off with productivity, quality, and environmental impact.

The main **objectives of the NUTRI2CYCLE project** are:

- map and comprehensively present the current flows and gaps in C, N and P cycles in 8 investigated agro-typologies over three major agricultural pillars;
- implement a toolbox with for stakeholders' comprehensible indicators to measure, sustainability & evaluate trade-offs between the current practice and innovative, optimized farming systems for the investigated typologies;
- innovation funnel;
- further development and testing of minimal 1-2 prototype per farm typology considering the different agro-climatological and socio-economic aspects;
- impact calculation at 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).

One of the specific objectives about assessing the microeconomic consequences of introducing selected new technologies in relevant farming typologies across Europe have been addressed through this report, which deals with the financial and economic effects of the implementation of the new selected technologies on the farm-scale level.

Regarding the objective about scrutinizing and prioritize 1 to 2 innovations per agro-typology (12-16 in total) for further full scale demonstration and in-depth impact investigations, within this report, in total, 16 technologies were analysed at the economic level through cost benefit analysis (CBA).

In the Nutri2Cycle project a range of solutions are developed among **5 research lines**:

1) **innovative soil, fertilisation and crop management systems and practices for enhancing N, P efficiency and increasing soil OC content;**

2) **substituting primary resources with biobased products;**

3) **novel animal feeds produced from agro residues;**

4) **innovative management systems, tools, and practices for optimized nutrient and GHG management in animal husbandry;**

5) **tools, techniques, and systems for higher-precision fertilisation.**

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2.1 Definition of the objective of the study

This report (Deliverable 3.3) is part of WP3 – Impact assessment: determining the environmental, economic and agronomic impact of innovative solutions for closing C, N, P loops and benchmarking these against the current baseline, Task 3.3. Cost-benefit analysis of proposed innovations, which will quantify the impact (at farm-level) of agroecology systems by a comprehensive toolbox (techno-economic and environmental).

Deliverable 3.3 deals with the financial and economic effects of the implementation of the new selected technologies on the farm-scale level. One established method to evaluate economic effects is the cost-benefit analysis (CBA). CBA is an analytical tool for assessing the economic advantages or disadvantages of one or more investments by calculating the costs and benefits to assess the common welfare change attributable to it.

This CBA report is primarily done to answer the question **'which of the new selected innovative technologies are cost-effective and sustainable for farmers?'**

Within this CBA-study, priority solutions identified within each of the higher indicated 5 research lines will be assessed.

2.2 Per research line

To cover a wide range of the proposed solutions in the NUTRI2CYCLE work plan, 5 technical research lines of the project were chosen.

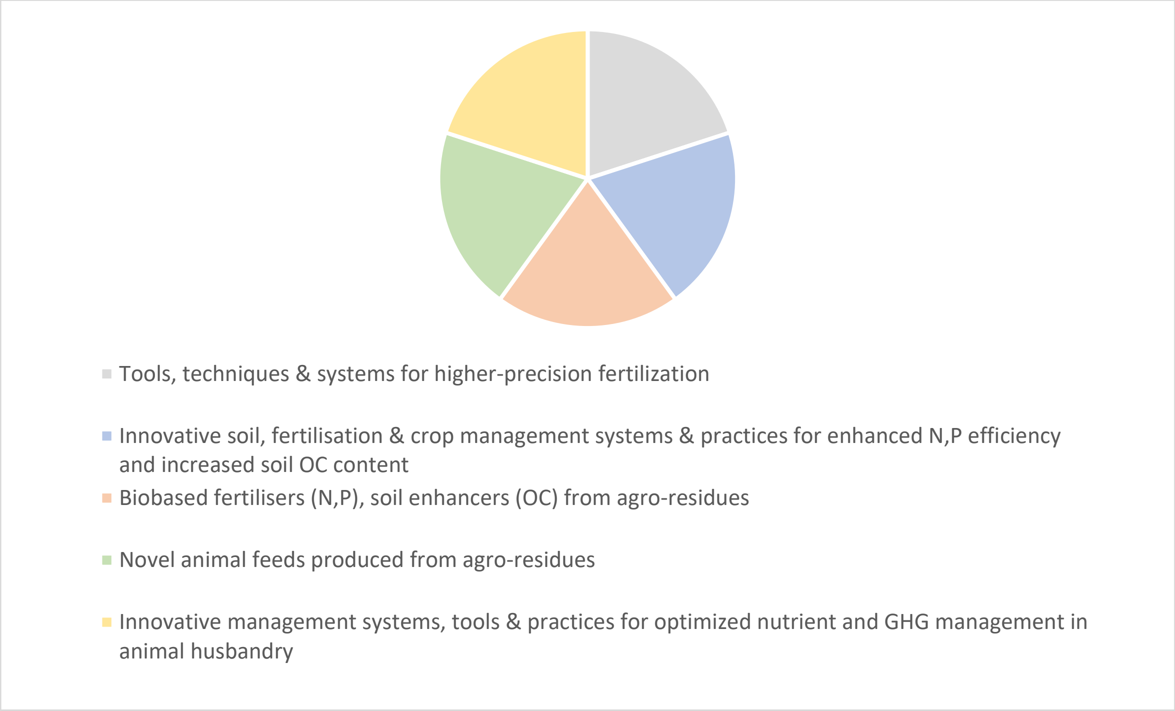

Figure 1. NUTRI2CYCLE Research lines

After the prioritization of technologies, 18 technologies were selected to be further researched in detailed impact studies. Those could an ecological, economic or social assessment. An overview of this selection is listed in Table 1.

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Table 1. Overview of the priority list solutions analysed

RL	SL#	LL#	Long-list abstract title	D3.2	EInS	eLCA	sLCA	CBA
1	17	18	Slurry acidification with industrial acids to reduce NH3 volatilisation from animal husbandry			x	x	
1	13	10	**Small/Farm scale AD of agro residues to increase local nutrient cycling & improve nutrient use efficiency**	x				x
1	15	24	**Adapted stable construction for separated collection of solid manure and urine in pig housing**	x				x
2	1	16	**Using digestate, precision agriculture and no-till focusing on OM stocking in an area characterized by the lack of it.**	x				x
2	2	17	**Crop farmer using a variety of manure & dairy processing residues to recycle and build soil C, N, P fertility**	X		x	x	x
3	19	30	**Precision farming coping with heterogeneous qualities of organic fertilisers in the whole chain**	X	x		x	x
3	23	13	Sensor technology to assess crop N status	X	x		x	
3	21	73	**Precision arable farming using BBF in potato growing**	x				x
4	4	1	**Ammonium stripping / scrubbing and NH4NO3 as substitute for synthetic N fertilisers**	X		x	x	x
4	4	2	**Ammonium stripping / scrubbing and NH4SO4 as substitute for synthetic N fertilisers**	X		x	x	X
4	4/7	6/43	**Concentrate from vacuum evaporation/stripping as nutrient-rich organic fertiliser**	X		x	x	x
4	4	9	**The liquid fraction of digestate substitute mineral N&K**	x				x
4	6	49/65	**N and P recovery from pig manure via struvite crystallization & design of struvite based tailor-made fertilisers**	X		x	x	x
4	7	55	Manure processing and replacing mineral fertilisers in the Achterhoek region	X		x	x	
4	7	20	**Low temperature ammonium-stripping using vacuum**	X		x	x	x
4	8	22	**BIO-PHOSPHATE: high temp. reductive thermal process recovery of concentrated P from animal bones**	x				x
5	9	40	Insect breeding as an alternative protein source on solid agro-residues (manure and plant wastes)			x	x	
5	12	41	**Floating wetland plants grown on liquid agro-residues as a new source of proteins**	X		x	x	x

D3.2 indicates the priority list solutions, in bold those included for economic analysis (CBA) in this report. EInS = Environmental indicator study, eLCA = Environmental life cycle assessment, sLCA = Social life cycle assessment. In the last column it is indicated for which solutions economic Cost Benefit Analysis (CBA) was also conducted.

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All the priority listed solutions will be economically assessed in this CBA study. For the ecologic and social assessment – see D3.4 of the Nutri2Cycle project). It was decided to combine some of the priority listed solutions, as otherwise, the overlap between the technologies would be too significant. In addition to that, economic research that was already performed in other projects was recovered to a maximum, as to make sure to build upon already existing knowledge.

This results in the following list of solutions for which CBA studies will be conducted:

For **Research line 1** the following technologies are assessed:

- **LL#10** Small/Farm scale anaerobic digestion of agro residues to increase local nutrient cycling & improve nutrient use efficiency
- **LL#24** Adapted stable construction for separated collection of solid manure and urine in pig housing (followed by separate post-processing)

For **Research line 2**:

- **LL#16** Using digestate, precision agriculture and no-tillage focusing on OM stocking in an area characterized by the lack of OM in sandy soil

  This technology was already researched in the Horizon Systemic project. The results and conclusions were included in this CBA assessment to be able to make a full comparison between technologies

- **LL#17** Crop farmer using a variety of manure and dairy processing residues to recycle and build soil C, N, P fertility

For **Research line 3**:

- **LL#30 + LL#73** Precision farming using bio-based fertilizers
  Given the overlap, in the technologies, LL#30 and LL#73 will be jointly assessed

For **Research line 4**:

- **LL#1 + LL#2** Ammonium stripping/scrubbing and using products as a substitute for synthetic N fertilizers
  Given the overlap, in the technologies, LL#1 and LL#2 will be jointly assessed
- **LL#9** Liquid fraction of digestate as a substitute for mineral N & K fertilizer
- **LL#65 + LL#49** Struvite as a substitute for synthetic P fertilizer
  Given the overlap, in the technologies, LL#65 and LL#49 will be jointly assessed
- **LL#22** BIO-PHOSPHATE: high temperature reductive thermal process recovery of concentrated Phosphorus from food grade animal bones
- **LL#20** Low-temperature ammonium-stripping using vacuum
- **LL#6 + LL#43** Concentrate from vacuum evaporation/stripping as nutrient-rich organic fertilizer
  Given the overlap, in the technologies, LL#6 and LL#43 will be jointly assessed

For **Research line 5**:

- **LL#41** Floating wetland plants grown on liquid agro-residues as a new source of proteins.

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Methodology

3.1 Step 1: setting the framework

This CBA assessment is meant for stakeholders to be able to economically evaluate the different priority solutions that are researched in the Nutri2Cycle project. To be able to compare different technologies to one another, it is important to define a clear framework, as this will assure to make the analysis as accurate as possible. Both a clear **“functional unit”** and a **“reference scenario”** will set the framework within which the evaluation can be done.

3.1.1 Functional unit

The “functional unit” is to be seen as the “process boundaries” within which the economic evaluation is performed. It is the basis for making the comparison between different technologies or management programs.

For example – when doing the comparison of fertilizers, the functional unit is set to 1 ha of arable land. To make an overall evaluation for the stakeholder’s own company, the CBA-result on the functional unit can be extrapolated to the company level: e.g. the farmer that cultivates 100 ha can easily estimate the impact by multiplying the functional unit by the total amount of hectares covered by his company.

Table 2. Overview of the functional units as selected for the priority-list solutions

Research line	**Technology**	#LL	Functional Unit
1. Innovative solutions for optimized nutrient & GHG in animal husbandry	Small/Farm scale anaerobic digestion of agro residues to increase local nutrient cycling & improve the nutrient use efficiency	**10**	1 ton of manure disposed
	Adapted stable construction for separated collection of solid manure and urine in pig housing (followed by separate post-processing)	**24**	1 ton of manure disposed
2. Innovative soil, fertilisation & crop management systems & practices	Using digestate, precision agriculture and no-tillage focusing on OM stocking in an area characterized by the lack of OM in sandy soil	**16**	1 ha of arable land
	Crop farmers use a variety of manure and dairy processing residues to recycle and build soil C, N, P fertility soil C, N, P fertility	**17**	1 ha of arable land
3. Tools, techniques & systems for higher-precision fertilization	Precision farming using bio-based fertilizers	**30 + 73**	1 ha of arable land
4. Biobased fertilisers (N, P) and soil enhancers (OC) from agro-residues	Ammonium stripping/scrubbing and NH_4NO_3 / $(NH_4SO_4)_2$ as substitutes for synthetic N fertilizers	**1 + 2**	1 ha of arable land
	The liquid fraction of digestate as a substitute for mineral N & K fertilizer	**9**	1 ha of arable land
	Concentrate from vacuum evaporation/stripping as nutrient-rich organic fertilizer	**6 + 43**	1 ha of arable land
	Struvite is a substitute for synthetic P fertilizer	**49 + 65**	1 ha of arable land
	Low-temperature ammonium stripping using vacuum	**20**	1 ha of arable land
	BIO-PHOSPHATE: high temperature reductive thermal process recovery of concentrated Phosphorus from food grade animal bones	**22**	1 ton of mineral fertilizer
5. Novel animal feeds produced from agro-residues	Floating wetland plants are grown on liquid agro residues as a new source of proteins	**41**	1 ton of biological effluent disposed

3.1.2 Reference scenario

When doing the CBA assessment, the implementation of the novel solution will always have to be compared to the current (financial) situation, i.e. the reference scenario. As this reference scenario is different for every stakeholder, it is not possible to define a scenario that would fit all stakeholders. Therefore, the reference scenario selected for making the comparison is defined based on the most common situation in the region.

Further in this document, the CBA will be performed on each of the technologies, with each time a clear and detailed indication of the reference scenario that applies for that technology. In general, the following reference scenarios will be followed:

Table 3. General overview of the reference scenarios used for doing the CBA

Functional unit	**Region**	
	Manure intensive	**Manure extensive**
1 ton of manure disposed	Not possible to be disposed on own arable land	Possible to dispose of own arable land and generate an income
1 ha arable land	Basis fertilization: manure On top: mineral fertilizers	Basis fertilization: mineral fertilizers
1 ton of mineral fertilizer	Standard used mineral fertilizers based on the recommendations of the local authorities (CAN, Urea, KCl, Triple Super Phosphate, …)	
1 ton of biological effluent	Disposal on land (as manure)	n.a.

3.2 Step 2: Collecting Data

Data within this report were collected from various sources, including a review of the literature on the web, Advisory services and the Ministries of Agriculture in Croatia and Belgium, other projects (ongoing and finished), information and experience from the involved sector and (to a big extent) the data collected under the WP2.

Data for Flanders – as the reference for the "manure intensive region"- were extrapolated from multiple online available sources such as official website of the Flemish government bodies. Specific data regarding environmental, nature, spatial planning and energy legislation in Flanders are based on information collected via Vlaamse Instelling voor Technologisch Onderzoek (VITO). For fertilization needs in Flanders data are based on statistics of Vlaamse Landmaatschappij (VLM).

General information about Belgian market trends such as crop yields, fertiliser prices, energy prices and other similar information in the report are compiled from several online data compilation platforms (e.g. IndexMundi, Konema, Numbeo and Eurostat). This information was also verified by stakeholders and consultants directly involved in the sector in Flanders.

For Croatia – as the reference for the manure extensive region - the report used data from the Advisory service of the Ministry of Agriculture and the Market Information System for data on the price and yield of certain agricultural crops in Croatia. Data from the Advisory service were also used for the recommendations of the fertilization management in Croatia.

For statistical data, such as data on crop production, areas used by certain crops, average yield, and crop output in total gross output in EU countries, Eurostat data were used. Data from the Croatian Bureau of Statistics were used for these data in Croatia.

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For fertiliser prices in Croatia, an overview of the market trends was made, and based on the collected data, the average price was calculated. The same method was used for calculating prices for GPS locators as well as drones for precision farming.

Information on specific scientific data to validate claims made in the report was compiled from various scientific research papers, articles, reports and other similar types of scientific work. A compiled list of all such literature is present in the references section as well as all other resources used in this report.

In order to provide the stakeholders a clear overview of the data resources a data-overview is given at the end of every assessment.

3.3 Step 3: CBA evaluation per technology

After setting the boundary conditions and collecting all necessary data the CBA evaluation was performed. Where relevant and an added value the N2C-solution was not only compared to the reference scenario, but also other scenarios were included for making the comparison.

Depending on the type of solution assessed the approach of doing the CBA is different. For those solutions in which there is a clear "market value" for all the economic elements (e.g. investment costs, market value of end-products, …) the CBA can be performed taking into account the additional investment (compared to the reference situation). This type of CBA will result in clear and defined economic values like an indication of the pay-back period, the overall yearly balance, etc.

On the other hand there are also N2C solutions where the market value of some of the economic aspects is not defined yet. In this situation the CBA will be done by doing a "back-calculation". This type of CBA will result in a maximum (or minimal) market value that the N2C-solution can have in order to be economically sustainable. In this case on cannot define a certain pay-back period or overall balances, but the outcome can be used for guiding both the farmers and other involved stakeholders to "acceptable" economic values.

In cases where functional unit is arable land, the methodology was based on the Gross Margin Calculation (GMC). The GMC also known as the gross profit margin ratio is a profitability ratio that compares the gross margin of a company to its revenue. It shows how much profit a company makes after paying off its Cost of Goods Sold. The GMC calculation in the document distinguishes the segment of total income that is generated according to the yield and unit price, and the segment of costs (including both production and harvesting costs). At the bottom line, GMC is performed based on the levels of crop prices (from lower to higher price).

3.4 Step 4: Comparison between the regions

For each of the researched solutions the economic evaluation is done for both the manure extensive and the manure intensive region. This approach is chosen to research whether the impact of current nutrient-availability on the market uptake for the N2C-solutions researched.

For both regions the functional unit was identical, though the reference situation and the market values were based on the actual region.

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3.5 Technologies compared

Table 4. NUTRI2CYCLE technologies and baseline scenarios

TECHNOLOGIES	LL#	ARABLE LAND	COMPARISON TO SYNTHETIC FERTILIZERS	REGULAR MANURE DISPOSAL
Small/Farm scale anaerobic digestion	10			🟩
Adapted stable construction for separated collection of solid manure and urine in pig housing (followed by separate post-processing)	24			🟩
Using digestate, precision agriculture and no-tillage focusing on OM stocking in an area characterized by the lack of OM in sandy soil	16	🟩		
Crop farmers use a variety of manure and dairy processing residues to recycle and build soil C, N, P fertility	17	🟩		
Precision farming using bio-based fertilizers	30 + 73	🟩		
Ammonium stripping/scrubbing and $NH_4NO_3/(NH_4)_2SO_4$ as substitute for synthetic N fertilizers	1/2		🟩	
The liquid fraction of digestate as a substitute for mineral N&K fertilizer	9		🟩	
Concentrate from vacuum evaporation/stripping as nutrient-rich organic fertilizer	6 + 43		🟩	
Struvite as a substitute for synthetic P fertilizer	49 + 65		🟩	
Low-temperature ammonium stripping using vacuum	20		🟩	
BIO-PHOSPHATE: high temperature reductive thermal process recovery of concentrated Phosphorus from food grade animal bones	22		🟩	
Floating wetland plants are grown on liquid agro-residues as a new source of proteins	41			🟩

4. Research Line 1: Innovative solutions for optimized nutrient & GHG in animal husbandry (LL#10 and LL#24)

4.1 LL10 Small/Farm scale anaerobic digestion

The purpose of small/farm scale anaerobic digestion is to digest on-farm residues (manure and possible crop residues) to produce on-site renewable energy. Furthermore, greenhouse gases from manure storage may be reduced by the application of this technique while there is less need for fossil fuels. There is an operational group in Flanders investigating this subject, consisting of Inagro, Boerenbond, Biogas-E, Innovatiesteunpunt, Hooibeekhoeve, Innolab and 40 farmers who have a pocket digester on the farm.

Most small-scale digesters in Belgium have a power output of 10 kW and digest 5-10 m³ manure daily. In Belgium, there are approximately 50 operative units (mostly on cattle farms and therefore mono-digestion of cattle manure).

Leeks (*Allium ampeloprasum var. Porrum*) are an important source of crop residues. The cultivation of leeks is an integral part of the agricultural sector in Belgium and large volumes of leek residues are produced in the process. Next to crop residues, animal manure is available in large quantities at some farms and poses significant challenges to the environment, mostly because of the uncontrolled emissions.

Small scale anaerobic digestion of agro residues is a good option to reduce nitrogen losses from crop residues and greenhouse gases from storage. The potential of expanding this technique to other agro residues is huge because of their wide availability. Other types of agro residues also show potential.

Figure 2. Leeks plantation

Where the research for the use of crop residues in small scale digesters is still ongoing, the digestion of farmer-own manure in small scale digesters is well-known but still improving. Taking into account that in order to keep the legal framework simple and robust it is important that only the **farm-own waste flows** (manure & crop residues) are taken into account for the economic evaluation. Therefore the focus is on the valorisation of manure in the small scale digester – as crop-residues will always be a marginal flow compared to the bigger availability of manure on a regular farm.

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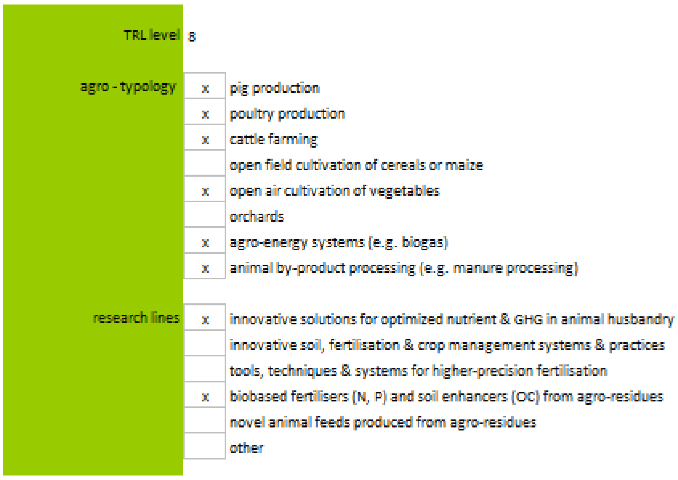

TRL level	8	
agro - typology	x	pig production
	x	poultry production
	x	cattle farming
		open field cultivation of cereals or maize
	x	open air cultivation of vegetables
		orchards
	x	agro-energy systems (e.g. biogas)
	x	animal by-product processing (e.g. manure processing)
research lines	x	innovative solutions for optimized nutrient & GHG in animal husbandry
		innovative soil, fertilisation & crop management systems & practices
		tools, techniques & systems for higher-precision fertilisation
	x	biobased fertilisers (N, P) and soil enhancers (OC) from agro-residues
		novel animal feeds produced from agro-residues
		other

Figure 3. LL10 Technology TRL, agro-typology and research lines

4.1.1 Background information

Manure disposal

- ***Manure intensive region (Flanders)***

The region of Flanders is known to be a region in which there is a surplus of manure compared to the demand for nutrients for fertilizing available arable land. That means that a significant part of the manure that is produced in Flanders is eventually treated in centralised “manure treatment systems”. In Flanders, there are 3 main types of “manure treatment systems”: (i) large scale digesters, (ii) composting facilities, and (iii) biological treatment installations. The combination of different technologies (e.g. combining digestion and biological treatment) in one site is also a possibility.
Where digestion as such does not remove or recover nutrients, the digestate (or the digestate products that can be recovered from this flow) can be a valuable nutrient source. Also, the composting of the thick fraction (of manure and/or digestate) resulting of separation into a thick and a thin fraction does result in a valuable soil enhancer that can even be exported. When the thin fraction (of manure and/digestate) is treated in biological treatment nutrients are not recovered but are removed (shifting ammonia (NH_3) to nitrogen gas (N_2) that is lost in the atmosphere).

The Figure 4. shows the availability of different manure treatment systems in the region of Flanders. It shows a higher density in the region of West-Flanders and the north of the Province Antwerpen, as these are the regions with the higher number of pig farms.

Figure 4. Overview of most of the manure treatment systems in the region of Flanders. Green silo = digesters, open (grey) silo = aerobic treatment, brown pile = composting facility (link)

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The disposal of manure from husbandry farms is usually done in the following order:

1. Dispose as much as possible of the manure on the arable land within the own management (up to the legal limits)
2. Dispose of as much as possible of the manure to arable land of neighbouring farmers (up to the legal limits)
3. Dispose of the remainder of the manure to a (external) manure treatment system

The costs for disposing manure (or digestate) at an external manure treatment installation can vary, but on average the following can be assumed (data received from stakeholders in the sector 2021):

- Disposal of chicken manure: 3 – 8 €/ton
- Disposal of raw manure: 15 – 20 €/ton
- Disposal of thin fraction: 12 – 17 €/ton
- Disposal of Thick Fraction of manure (for composting): 12 – 20 €/ton
- Disposal of digestate: 25 – 30 €/ton

- ***Manure extensive region (Croatia)***

The situation in Croatia is completely different as there is no excess of manure, and the raw manure is even to be considered as a source of income for the farmers as they can sell the raw manure for 10.5 €/ton. Thick fraction of manure has even a higher market value of around 40 €/ton.

Disposal of agro-waste

Agro-waste is available in the majority of the farms, though the volume in which it can vary greatly. The risk of GHG emissions from that agro-waste is often underestimated, as some of those waste-flows have a high nitrogen content and can therefore be a source of emissions.

- ***Disposal of agro-waste in Flanders***

In Flanders around 449.000 ton of agro-waste (food waste) originated from the agricultural sector in 2015 (link). Of this volume around 63 % originated in the horticulture sector, 32 % in arable farming and 5 % in livestock farming. The horticulture is with a total of around 280.000 ton of food waste per year the major contributor, with leeks (± 85.000 ton/year), onions (± 34.000 ton/year) and spinach (± 20.000 ton/year) the most important. But also, arable farming has a significant contribution with a total volume of ± 93.000 ton/year of food waste originating from the potato-sector. The food waste originating from the livestock farming was in 2015 only limited to around 23.000 ton/year.

But not all of this agro-waste is available on the farms: currently the majority of the waste (70 %) returns to the soil by ploughing in, and 11 % is destined for animal feed (livestock feed). Only 8 % is valorised in anaerobic digestion or composting. A remainder of only 6 % of the total agricultural waste is currently defined with an “unknown destination”.

Within the Flemish legal framework, it is possible to perform onsite anaerobic digestion and composting at small scale. As long as all the input and output flows come from and remain on the parcels linked to the own company the follow-up is rather limited. Only when growing to a bigger scale and doing the valorisation of input from other farmers and/or handling with the digestate products or compost the legal framework within which has to be operated, it becomes a lot more complex. The technology focused on within the Nutri2Cycle project is based on the small-scale and on farm digestion of agro-residues for the production of energy.

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- ***Disposal of agro-waste in Croatia***

It is estimated on average around 10 million tons of agricultural waste, co-products and by products are generated yearly in Croatia. The largest volumes generated are by the livestock sector, fruit, cereal and vegetable value chains (link). Technical available potential agricultural residues in Croatia are estimated to be 492.730 t of corn stover and 622.752 tons of wheat straw (link).

In 2017. the amount of biowaste used for anaerobic digestion in Croatia was 46.546 tons. Majority of the waste used comes from processing industry (99 %) (link). The most often used medium for biogas production in Croatia is manure (50 – 60 %, mainly from cow breeding, also from pigs or poultry), corn (or grass) silage (25 – 35 %), and other available biodegradable feedstocks (5 – 25 %) (link).

Energy consumption and production at the farm level

The consumption of energy is a significant cost within an agricultural company, certainly for those companies involved in animal husbandry. As rules of thumb, the following main energy consumers can be considered as shown in the table below.

Table 5. Main energy consumers on farms (link)

Sector	Subtype	Electricity consumption	Heat consumption	Unit
Dairy Farms	Milk robots	79	-	kWh/1.000 litre milk
	Classical systems	44	-	kWh/1.000 litre milk
Beef Cattle		8	-	kWh/cattle.year
Pig farms	Sow husbandry	164	585	kWh/sow.year
	Fattening pigs	21	46	kWh / pig place.year

For the region of **Flanders,** the installation of solar panels on farms is gradually increasing to produce electricity. Nevertheless, only 6,5 to 9 % of the total roof surfaces (including farms, companies, houses) that could be used for solar panels are utilized in 2020, indicating that there is still a significant possibility for expansion of solar energy (*VEKA – Provincies.incijfers.be – 2018-2020*). The implementation of PV on farm level can be assumed to be slightly higher than the average level in Flanders, as farms often have both higher energy expanses and at the same time a bigger surface available. Therefore, it can be considered that for the energy consumed on farms, around 15 – 20 % of the electricity is produced by on-site photo-voltaic in Flanders.

In 2020, **Croatia** had an installed solar power capacity of 108.5 MW, generating 95.5 GWh of electricity (source). However, there is no available data on solar energy production on farms. The president of the Croatian Chamber of Agriculture notes that the agricultural sector's contribution to renewable energy is only 2.7%, much lower than the EU average (link). Despite the potential long-term benefits, such as cost reduction and increased sustainability, many Croatian farmers are unaware of the advantages of solar panel implementation. On average, agricultural investments in solar systems amount to around 50,000 HRK (6,600 €) for smaller plants covering about 70 % of a farm's energy needs (link).

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- ***<u>Evolution in energy costs</u>***

In Flanders the price of electricity is increasing significantly. From 2018 up to September 2021 the average price of electricity taken from the grid varied between 0.22 €/kWh and 0.24 €/kWh for companies consuming around 50.000 kWh per year (Figure 5). Since November 2021, the price is going up, and in the beginning of 2022 (January & February) the price increased with 66 % compared to the price of September 2021. Of course, it is pure speculation how the price will evolve in the (near) future, though it is expected that the price will go down but will most probably not reach the former price levels anymore.

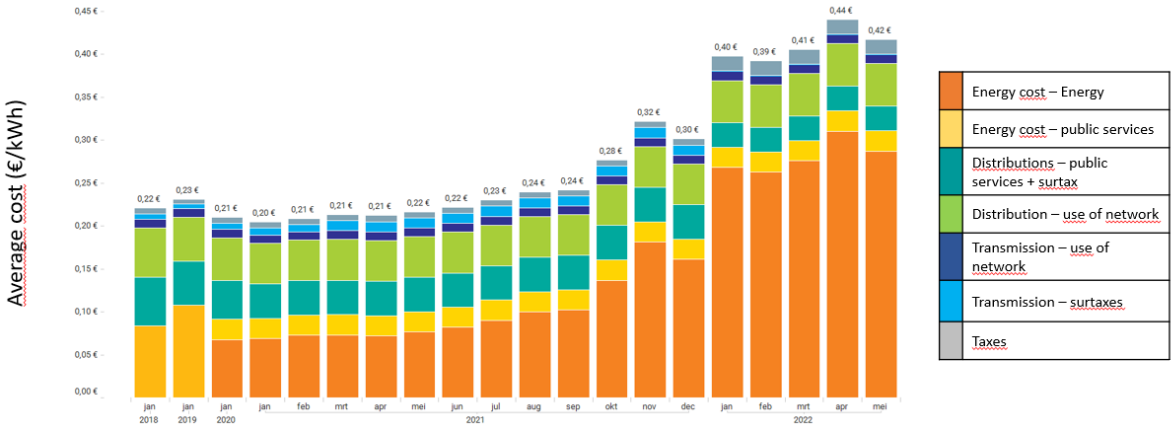

Figure 5. Evolution of the electricity prices €/kWh$_e$ (<u>link</u>)

The Figure 6. shows the electricity price for households in Croatia between 2010 and 2020. It also shows a stable flow for this period.

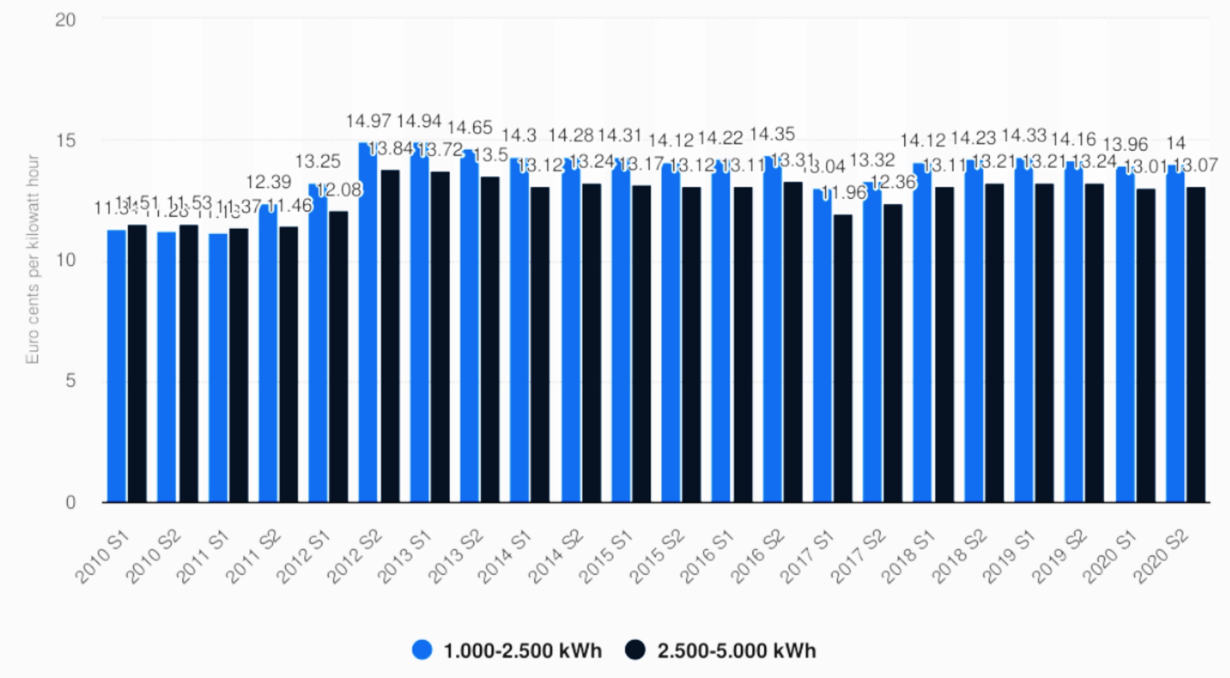

Figure 6. Electricity prices for households in Croatia from 2010 to 2020 (<u>link</u>)

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Not only the cost of electricity should be considered, but also the expenses for the use of natural gas for heating. The price of natural gas is increasing significantly as can be seen in the figure below for a company consuming around 116.280 kWh per year.

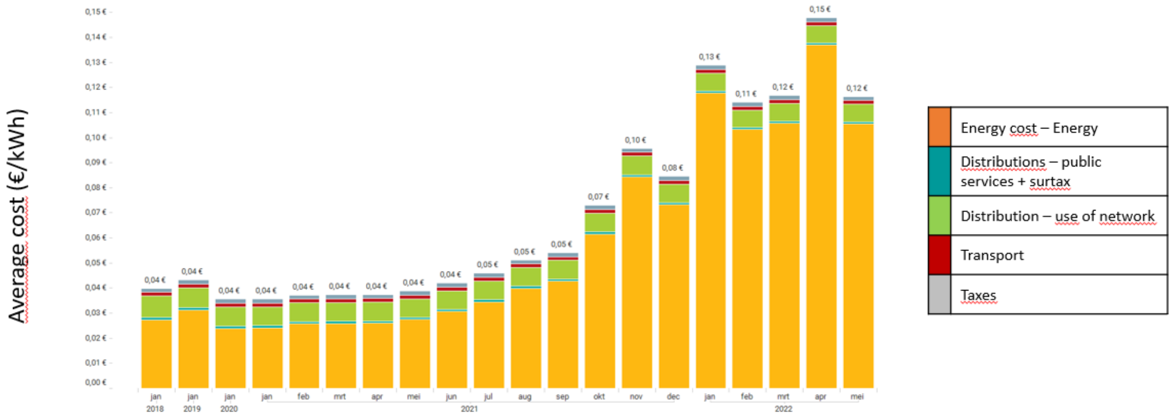

Figure 7. Evolution of the price of natural gas €/kWh$_{th}$ (link)

4.1.2 N2C case scenario

The N2C scenario consists of the implementation of a small-scale digester on an agricultural farm. The ton of manure that would be otherwise disposed of in a (centralised) manure treatment plant will now first pass a small-scale digester installation on the farm site. The small-scale digester is a mono-digester (on piggery manure) in which **only on-farm residues** can be digested.

The Table 6. shows the main process parameters to be considered when installing the small-scale digester on manure. These data originate from the research done in WP2 of the Nutri2Cycle project (Deliverable 2.6) and former research done by Inagro.

Table 6. Main process parameters of a small-scale digester (link)

Per ton of manure		Cattle slurry	Pig Slurry	Pig manure (thick fraction)
INPUT	% DM	9.83	8.15	25.6
	% OM	7.54	5.85	21.1
	N_{tot} (kg/ton)	4.31	5.6	10.5
	P_2O_5 (kg/ton)	1.6	3.9	9.48
	K_2O (kg/ton)	4.33	5.25	7.14
OUTPUT (digestate)	% DM	6.54	15.03	
	% OM	4.69	10.53	
	N_{tot} (kg/ton)	3.91	9.6	
	P_2O_5 (kg/ton)	1.4	7.6	
	K_2O (kg/ton)	4.33	6.75	
OUTPUT (biogas)	Nm^3	25	25	
OUTPUT (energy from small scale cogeneration unit)	kW_e (electricity) /ton	35	35	
	kW_{th} (heat)/ton	75	75	

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Combining this information with the above indicated energy consumption (Table 5), the following conclusions can be made:

- By digesting the manure coming from a fattening pig more energy (heat and electricity) than the actual demand for the animal can be produced;
- As more energy is required for sow husbandry, the energy coming from digesting the manure from the sows can only cover up to 55 % of the heat requested and 90 % of the requested electricity.

Table 7. Overview of the amount of manure produced and energy consumed per fattening pig and sow

	Amount of manure produced /year	Electricity required	Heat required
1 Fattening pig (per place)	1.2 – 1.6	21 kWh_e	46 kWh_{th}
Amount of digested manure required for producing the necessary energy for the fattening pig (1 ton manure = 35 kW_e and 75 kW_{th})		0.6 ton	0.61 ton
1 sow (per place)	4.0 – 4.6	164 kWh_e	585 kWh_{th}
Amount of digested manure required for producing the necessary energy for the sow (1 ton manure = 35 kW_e and 75 kW_{th})		4.7 ton	7.8 ton

A conclusion that can be drawn from Table 7 is that when housing only fattening pigs there will be an energy overproduction (when digesting all the available manure), but when housing only sows there would be a shortage. The ideal situation is therefore the combination of both housing sows and fattening pigs. This combination of fattening pigs and sows are often implemented on farmer sites, creating possibilities for having a balanced energy system when implementing small scale digestion.

When implementing a small-scale digester at a farm site, an investment is needed for the following parts:

- The digester in which the manure is transformed to biogas
- A cogeneration unit in which the biogas is transformed into electricity and heat.
- Digestate storage
    - When the digestate would be applied on own land the minimum storage capacity needs to meet the amount of digestate produced in 6 months' time
    - When the digestate is disposed on a more regular basis to a manure treatment plant, the minimum storage capacity can be limited
- Infrastructure
    - Additional piping and pumping equipment
    - Concrete, fundaments, etc.
- Legal framework (permits, net study, obligated instrumentation, etc,.)

The total investment cost for a small-scale digester of course differs with the scale. The bigger the scale, the higher the scale-advantage. The investment for a 20 kWe installation ranges at the time of the study between 150.000 and 200.000 €; whereas a 40 kW_e installation corresponds to an investment of 200.000 – 350.000 kWe.

4.1.3 Financial/Economic analysis - Reference scenario

The reference scenario for the implementation of the small-scale digesters on agro-waste consists of a farm that corresponds to the following assumptions:

- The farm has no land available for the disposal of its own manure, what makes that there is a need for disposal of manure to centralized external manure treatment plants;
- The manure is transported straight from the manure storage to the manure treatment plant;
- There are no solar panels available on the farm;
- The stable construction is classic (with a manure storage underneath the stable & air treatment for reducing the emissions);
- It is a piggery farm (fattening pigs & sow husbandry) with a significant energy request;
- Thermal energy for heating the stables is only required in winter times (i.e. 6 months per year)

The legal framework in Flanders (VLAREM legislation) defines the forfeit amount of manure produced in pig farms being 1 fattening pig to produce 1.2 to 1.6 ton of manure per year, where a sow produces 4 to 4.6 tons per year. Combining this information to the energy consumption as indicated above, the following Table 8. can be deducted giving an overview of the cost for linked 1 ton of manure in a manure intensive region. This shows that in a manure intensive region the cost per ton manure produced is 22.7 €/ton for a fattening pig, and 33.5 €/ton for a sow.

Table 8. Calculation of the costs per ton manure produced for the reference situation in Flanders (taking into account the costs for energy & disposal of manure based on the costs per kWh and ton given above))

Manure intensive region		Ton manure produced / year		Electricity required		Heat Required	
1 Fattening Pig		min	max				
	Ton/pig place	1,2	1,6				
average		1,4	Ton/pig place	21	kWe	46	kWth
Cost per unit (Average 2018 - 2021)	€/unit	**17,5**	€/ton	0,24	€/kWh$_e$	0,05	€/kWh$_{th}$
	€/pig	24,5	€/pig	5,04	€/pig	2,3	€/pig
Total cost per pig		31,8	€/pig				
		22,7	**€/ton manure produced**				
1 Sow		min	max				
	Ton/pig place	4	4,6				
average		4,3	Ton/pig place	164	kWe	585	kWth
Cost per unit (Average 2018 - 2021)	€/unit	**17,5**	€/ton	0,24	€/kWh$_e$	0,05	€/kWh$_{th}$
	€/sow	75,25	€/sow	39,36	€/pig	29,25	€/pig
Total cost per pig		143,9	€/sow				
		33,5	**€/ton manure produced**				

When comparing the energy prices between Flanders and Croatia (cfr. Figure 5 and Figure 6) it shows that the costs for energy for Croatia are around 55 % of the costs for energy in Flanders. On top of that, the disposal of the manure is not to be considered as a cost, but rather as an income, as it can generate around 10.5 €/ton. Taking into account all these data, the cost per ton of manure produced will result in an income of about 1.7 €/ton (per sow) and 7.6 €/ton per fattening pig (Table 9).

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Table 9. Calculation cost per ton of pig manure produced in Croatia

Manure extensive region		Ton manure produced / year		Electricity required		Heat Required	
1 Fattening Pig		min	max				
	Ton/pig place	1,2	1,6				
average		1,4	Ton/pig place	21	kWe	46	kWth
Cost per unit	€/unit	**-10,5**	€/ton	**0,132**	€/kWh$_e$	**0,028**	€/kWh$_{th}$
(Average 2018 - 2021)	€/pig	-14,7	€/pig	2,772	€/pig	1,265	€/pig
Total cost per pig		-10,7	€/pig				
		-7,6	**€/ton manure produced**				
1 Sow		min	max				
	Ton/pig place	4	4,6				
average		4,3	Ton/pig place	164	kWe	585	kWth
Cost per unit	€/unit	**-10,5**	€/ton	**0,132**	€/kWh$_e$	**0,028**	€/kWh$_{th}$
(Average 2018 - 2021)	€/sow	-45,15	€/sow	21,648	€/pig	16,09	€/pig
Total cost per pig		-7,4	€/sow				
		-1,7	**€/ton manure produced**				

4.1.4 Cost Benefit analysis – Innovative scenario

The overall costs and incomes when implementing a small-scale digester at a pig farm in Flanders is indicated in Table 10. Data for the scenario with the small-scale digester were taken from the deliverable D2.6 of the N2C-project, in combination with the report from the PocketPower project (link). The same evaluation was done for a similar farm in Croatia. The value (price) of the pig meat is not considered, as the production of meat is not altered by installing a small-scale digester on site.

The main conclusions that can be drawn from this table are :

- For a manure intensive region, there is no direct additional benefit to installing a small scale digester. For the manure intensive region an additional income can be generated through subsidies;
- The cost per ton of manure remains almost unchanged for the manure intensive region (29.8 €/ton with a pocket digester vs. 30.82 €/ton without a pocket digester). Main reason for this is that the cost for digestate disposal is significantly higher then for raw manure;
- For a manure extensive region there is a clear drop in costs when installing a small scale digester: 2.05 €/ton$_{manure}$ with a digester vs. 7.32 €/ton$_{manure}$ without. The main gain is due to the reduced costs for energy;
- When installing a pocket digester on piggery manure, the farmer will save around 4.62 €/ton$_{manure}$ in the manure intensive region, and 5.27 €/ton$_{manure}$ in a manure extensive region.

The most important number for the evaluation of the investment is the "payback period". The payback period for a pocket digester (estimated as an investment of 175.000 € for a 5.000 ton/year installation) at a pig farm is around 7.5 year in Flanders. For the same investment in Croatia the payback period is a lot lower and only around 2 year – meaning that with the given investment subsidy and costs the investment in a small scale digester would be regained within 2 years' time.

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Table 10. Overview of the CBA assessment for the installation of a pocket digester at a pig farm

			Manure intensive		Manure extensive	
PIG Farm		Unit	Reference	With small scale digester	Reference	With small scale digester
Benefits	Disposal of manure				10,5	
	Disposal of digestate					10,5
	Subsidies (heat & power certificates)	€/ton	0	3,6		
	TOTAL BENEFITS	**€/ton.year**	**0,00**	**3,60**	**10,50**	**10,50**
Costs	Disposal of manure	€/ton$_{manure}$	17,5			
	Heating costs (average fattening pig & sow)	€/ton$_{manure}$	5,53		3,04	
	Electricity costs	€/ton$_{manure}$	7,8		4,3	
	Disposal of digestate	€/ton$_{manure}$		27,5		
	Labour	€/ton$_{manure}$		0,5 0,5hr per day, total cost labour of 40.000 €/year		0,25 0,5hr per day, total cost labour of 20.000 €/year
	Repair & maintenance	€/ton$_{manure}$		1,8 9000 €/year for 5000 ton installation		1,8 9000 €/year for 5000 ton installation
	Total COST	**€/ton$_{manure}$**	**30,82**	**29,80**	**7,32**	**2,05**
	OPEX balance (benefits - cost)	€/ton$_{manure}$	-30,82	-26,20	3,18	8,45
	OPEX benefit (by investment) (a)	**€/ton$_{manure}$**		**4,62**		**5,27**
Investment	Total investment Installation of 5.000 ton/yr	€		175000		175000
	Netto investment 70% subsidy on investment	€				52500
	Investment per unit (CAPEX) (b)	€/ton		35		10,5
	Annualized investment cost (c) 8 year	€/ton.year		4,38		1,31
	Overall yearly balance (a) - (c)	**€/ton.year**		**0,24**		**3,96**
	Payback period (b)/(a)	**year**		**7,58**		**1,99**

Impact of changes in the price of energy (sensitivity analysis)

The graphs above (Figure 5 to 7) indicate that the current costs linked to energy (electricity and gas) are almost double of the costs of former years. The Table 11. gives an overview for the impact of the costs of energy on the economic evaluation on the investment in a pocket scale digester.

As indicated above, the main parameter to do the evaluation is the "payback period".

For Flanders, it shows that with an increase of the energy prices to the situation with high energy costs (= reference situation 2022) will significantly lower the payback period from 7.5 years to only 2 years. It also shows that in the situation with even higher energy costs ("high extreme"), the small-scale digester would return itself financially in no more than 1 year.

For Croatia, on the other hand, a payback period of only 2 years can already be obtained with the average energy prices (reference year 2019). If the costs for energy would increase the payback period will drop to below 1 year. On the other hand, if the energy prices would drop significantly (= 50 %) below the prices of 2019, the payback period will increase up to 6.5 year.

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Table 11. CBA assessment with disposal of manure and digestate at an external treatment facility – impact of energy costs

	Manure intensive region		Energy costs				
			Low extreme (2019 -50%)	**Low** (2019 -25%)	**Average** **(**Ref 2019**)**	**High** (Ref 2022)	**High Extreme** (2022 +50%)
	Electricity unit price	*€/kWe*	*0,12*	*0,18*	*0,24*	*0,42*	*0,63*
	Heating unit price	*€/kWth*	*0,025*	*0,0375*	*0,05*	*0,12*	*0,18*
Benefits	Savings on Disposal of manure	€/ton manure	**17,5**	**17,5**	**17,5**	**17,5**	**17,5**
	Savings on Electricity costs	€/ton manure	3,9	5,8	7,8	13,6	20,4
	Savings on Heating costs	€/ton manure	2,76	4,14	5,53	13,26	19,89
	Savings on OPEX	**€/ton manure**	**24,16**	**27,49**	**30,82**	**44,39**	**57,84**
	Subsidies	**€/ton manure**	**3,6**	**3,6**	**3,6**	**3,6**	**3,6**
	Total Benefits	**€/ton manure**	**27,76**	**31,09**	**34,42**	**47,99**	**61,44**
Costs	Disposal of digestate	€/ton manure	**27,5**	**27,5**	**27,5**	**27,5**	**27,5**
	Labour	€/ton manure	0,5	0,5	0,5	0,5	0,5
	Repair & Maintenance	€/ton manure	1,8	1,8	1,8	1,8	1,8
	Total Costs	**€/ton manure**	**29,8**	**29,8**	**29,8**	**29,8**	**29,8**
	OPEX Balance (Benefits - costs)	**€/ton manure**	**-2,04**	**1,29**	**4,62**	**18,19**	**31,64**
Investment	Total investment (5.000 ton manure)	€	**-175000**				
		€/ton manure	-35				
	Annualized investment costs (8 year)	€/ton manure.year	-4,4				
	Overall balance (CAPEX + OPEX)	**€/ton.year**	**-6,42**	**-3,09**	**0,24**	**13,82**	**27,27**
	Payback period	**year**	**n.a.**	**27,20**	**7,58**	**1,92**	**1,11**

	Manure extensive region		Energy costs				
			Low extreme (2019 -50%)	**Low** (2019 -25%)	**Average** (Ref 2019**)**	**High** (Ref 2022)	**High Extreme** (2022 +50%)
	Electricity unit price	*€/kWe*	*0,066*	*0,099*	*0,132*	*0,231*	*0,3465*
	Heating unit price	*€/kWth*	*0,01375*	*0,020625*	*0,0275*	*0,066*	*0,099*
Benefits	Disposal of manure	€/ton manure	**-10,5**	**-10,5**	**-10,5**	**-10,5**	**-10,5**
	Electricity costs	€/ton manure	2,1	3,2	4,3	7,5	11,2
	Heating costs	€/ton manure	1,52	2,28	3,04	7,29	10,94
	Savings on OPEX	**€/ton manure**	**-6,84**	**-5,01**	**-3,18**	**4,29**	**11,69**
	Subsidies	**€/ton manure**					
	Total Benefits	**€/ton manure**	**-6,84**	**-5,01**	**-3,18**	**4,29**	**11,69**
Costs	Disposal of digestate	€/ton manure	**-10,5**	**-10,5**	**-10,5**	**-10,5**	**-10,5**
	Labour	€/ton manure	0,25	0,25	0,25	0,25	0,25
	Repair & Maintenance	€/ton manure	1,8	1,8	1,8	1,8	1,8
	Total Costs	**€/ton manure**	**-8,45**	**-8,45**	**-8,45**	**-8,45**	**-8,45**
	OPEX Balance (Benefits - costs)	**€/ton manure**	**1,61**	**3,44**	**5,27**	**12,74**	**20,14**
Investment	Net investment (5.000 ton manure, 70% subsidy)	€	**-52500**				
		€/ton manure	-10,5				
	Annualized investment costs (8 year)	€/ton manure.year	-1,3				
	Overall balance (CAPEX + OPEX)	**€/ton.year**	**0,30**	**2,13**	**3,96**	**11,43**	**18,83**
	Payback period	**year**	**6,51**	**3,05**	**1,99**	**0,82**	**0,52**

Impact of costs of disposal

As indicated above, the assessment done for the average situation in Flanders is based on the treatment of manure and digestate in an external treatment facility. In case the manure in the reference scenario would be disposed on land (i.e. disposal costs limited to transport (5€/ton$_{\text{manure}}$), and the same would be possible with the digestate (i.e. the costs for disposal would stay the same) the results also change significantly. In this situation the investment will increase though, as a bigger digestate storage unit would be required. But it shows that this investment is easily covered by the benefits gained by investing in the pocket digester: the payback period would then only be around 3 years for the energy prices of 2019.

Table 12. Overview of CBA analysis for Flanders when disposal of digestate manure on arable land would be possible (= low disposal cost)

	Manure intensive region		Energy costs				
			Low extreme (2019 -50%)	**Low** (2019 -25%)	**Average** (Ref 2019)	**High** (Ref 2022)	**High Extreme** (2022 +50%)
	Electricity unit price	*€/kWe*	*0,12*	*0,18*	*0,24*	*0,42*	*0,63*
	Heating unit price	*€/kWth*	*0,025*	*0,0375*	*0,05*	*0,12*	*0,18*
Benefits	Savings on Disposal of manure	€/ton manure	**5**	**5**	**5**	**5**	**5**
	Savings on Electricity costs	€/ton manure	3,9	5,8	7,8	13,6	20,4
	Savings on Heating costs	€/ton manure	2,76	4,14	5,53	13,26	19,89
	Savings on OPEX	**€/ton manure**	**11,66**	**14,99**	**18,32**	**31,89**	**45,34**
	Subsidies	**€/ton manure**	**3,6**	**3,6**	**3,6**	**3,6**	**3,6**
	Total Benefits	**€/ton manure**	**15,26**	**18,59**	**21,92**	**35,49**	**48,94**
Costs	Disposal of digestate	€/ton manure	**5**	**5**	**5**	**5**	**5**
	Labour	€/ton manure	0,5	0,5	0,5	0,5	0,5
	Repair & Maintenance	€/ton manure	1,8	1,8	1,8	1,8	1,8
	Total Costs	**€/ton manure**	**7,3**	**7,3**	**7,3**	**7,3**	**7,3**
	OPEX Balance (Benefits - costs)	**€/ton manure**	**7,96**	**11,29**	**14,62**	**28,19**	**41,64**
Investment	Total investment (5.000 ton manure)	€	**-225000**				
		€/ton manure	-45				
	Annualized investment costs (8 year)	€/ton manure.year	-5,6				
	Overall balance (CAPEX + OPEX)	**€/ton.year**	**2,33**	**5,66**	**8,99**	**22,57**	**36,02**
	Payback period	**year**	**5,65**	**3,99**	**3,08**	**1,60**	**1,08**

For the evaluation in Croatia the case is considered that the manure or digestate would not generate any income but would be disposed without costs (= 0 €/ton). This results in the overview below, what clearly shows that in this case the investment in a small-scale digester is economically sustainable even in the situation with low energy cost: the payback period remains around 3 years. If the energy prices would increase above the 2019 situation, the investment would even become more interesting with a payback period of only 0.8 years for the reference situation of energy prices in 2022. If energy prices would even further increase to the scenario of "2022 + 50 %" the investment in a small scale digester would be returned within half a year.

Table 13. Overview of CBA analysis for Croatia when disposal of digestate and manure on arable land would not generate an income

	Manure extensive region		Energy costs				
			Low extreme (2019 -50%)	**Low** (2019 -25%)	**Average** (Ref 2019)	**High** (Ref 2022)	**High Extreme** (2022 +50%)
	Electricity unit price	*€/kWe*	*0,066*	*0,099*	*0,132*	*0,231*	*0,3465*
	Heating unit price	*€/kWth*	*0,01375*	*0,020625*	*0,0275*	*0,066*	*0,099*
Benefits	Disposal of manure	€/ton manure	**0**	**0**	**0**	**0**	**0**
	Electricity costs	€/ton manure	2,1	3,2	4,3	7,5	11,2
	Heating costs	€/ton manure	1,52	2,28	3,04	7,29	10,94
	Savings on OPEX	**€/ton manure**	**3,66**	**5,49**	**7,32**	**14,79**	**22,19**
	Subsidies	**€/ton manure**					
	Total Benefits	**€/ton manure**	**3,66**	**5,49**	**7,32**	**14,79**	**22,19**
Costs	Disposal of digestate	€/ton manure	**0**	**0**	**0**	**0**	**0**
	Labour	€/ton manure	0,25	0,25	0,25	0,25	0,25
	Repair & Maintenance	€/ton manure	1,8	1,8	1,8	1,8	1,8
	Total Costs	**€/ton manure**	**2,05**	**2,05**	**2,05**	**2,05**	**2,05**
	OPEX Balance (Benefits - costs)	**€/ton manure**	**1,61**	**3,44**	**5,27**	**12,74**	**20,14**
Investment	Net investment (5.000 ton manure, 70% subsidy)	€	**-52500**				
		€/ton manure	-10,5				
	Annualized investment costs (8 year)	€/ton manure.year	-1,3				
	Overall balance (CAPEX + OPEX)	**€/ton.year**	**0,30**	**2,13**	**3,96**	**11,43**	**18,83**
	Payback period	**year**	**6,51**	**3,05**	**1,99**	**0,82**	**0,52**

4.1.5 Comparative analysis of innovative scenario and published research

In the domain of small/farm-scale anaerobic digestion, the focus is on processing on-farm residues like manure and crop residues to generate on-site renewable energy, thereby reducing greenhouse gas emissions and lessening dependence on fossil fuels. In Belgium, where most small-scale digesters (typically 10 kW output, processing 5-10 m^3 of manure daily) predominantly operate on cattle farms for mono-digestion, there is a continuous effort to emphasize the valorization of farm-owned manure for economic evaluation simplicity. Notably, the feasibility of pocket digesters varies based on factors such as energy prices and land availability for disposal.

Comparatively, the case study in Flanders, Belgium, represents a pocket digester at a pig farm, revealing a 7.5-year payback period. In contrast, an evaluation in Croatia yields a 2-year payback, attributed to lower costs and subsidies. The impact of doubled energy costs on economic assessment is evident, with Flanders experiencing a 2-year payback under higher energy prices and 1 year under extreme costs. Croatia, under the influence of cost increases, sees a sub-1-year payback, contrasting with 6.5 years with a 50 % energy price drop.

Expanding the comparison, external treatment of manure and digestate in Flanders results in a 3-year payback, even with land disposal. Similarly, in Croatia, assuming no income from manure or digestate disposal leads to a 3-year payback, underscoring economic sustainability.

Contrasting this with the case of the Van der Schans family in Den Eelder, Netherlands, who operate a fixed film SSAD plant on a dairy farm, notable differences emerge. Their system, initiated in 2014, digests 7500 m3 of dairy slurry and a small amount of wastewater, producing 480,000 kWh of electricity annually with a 65 kW CHP unit. The investment cost for this plant is disclosed at €300,000, with an additional €150,000 for the CHP unit. Operational costs, covering maintenance and labor, range between €15,000 and €20,000 yearly. Importantly, the Dutch case emphasizes CO2-neutral renewable energy production, treatment, and reuse of on-farm manures, with substantial estimated energy production and emission reduction (link).

Also in Flanders there has been the evaluation of the economic feasibility of a small scale digester at a piggery farm. This was done within the frame of the project Pocket Boer by Inagro. The results show that for a small scale digester on this pig farm considered in this study, the payback period would be around 5 year (investment of around 150.000 €, a yearly benefit of around 40.000 €/year and the yearly operational costs of around 10.000 €/year). This study takes into account additional possible subsidies in Flanders that were not considered in the N2C-evaluation, and it does not take into account the change in disposal costs that might occur when having to dispose the manure or digestate into an external facility. On top, it considers a higher biogasproduction as it assumes part of the manure to originate from a VedoWs-stable construction system. Overall, it can be concluded that the results of both studies (Pocket Power and Nutri2Cycle) are in the same order of magnitude (link).

In summary, the comparison highlights the intricacies and contextual differences between the small/farm-scale anaerobic digestion scenario in Belgium and Croatia and the fixed film SSAD plant scenario in the Netherlands. Each presents an approach to renewable energy production and emission reduction, shaped by specific agricultural contexts and technology configurations.

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

4.1.6 Conclusions

In short, the following conclusions can be made for the investment in a pocket digester:

- For a manure extensive region, the investment in a pocket digester (mono digester) appears to be economically sustainable as the payback period for the reference scenario 2019 is estimated at only 2 years. Only when the energy-prices would drop to the “low extreme” scenario the payback period would increase up to 6.5 year;
- In manure extensive regions the manure and digestate flow can generate an income. For doing this assessment the market value of both flows can be considered equal, as there is no nutrient removal nor up-concentration done in the pocket digester. In case there would be a difference in the market value this will have an impact on the payback period of the investment;
- For a manure intensive region the investment in a pocket digester for those farms that have enough land available for the disposal of manure seem feasible (pay-back period around 3 years for the reference situation of 2019). On the other hand, when having to dispose to a manure treatment facility the higher gate fee that has to be paid for disposing of digestate (compared to manure) will lower the economic viability of the pocket digesters (around 7.5 years of payback period);
- The impact of the energy costs on the economic feasibility of the pocket digesters is more significant for manure intensive regions: if the energy-costs of reference 2022 are considered the investment in a pocket digester will be interesting for all piggery farms in Flanders (also those with limited own arable land) as the payback period will drop to around 2 years.

Table 14. Overview of data used as reference to CBA study

Data	Reference CBA Study	Type of data	Source of data
Electricity and heat consumption – dairy farms	Table 5	Sector publication	https://www.enerpedia.be/nieuws
Electricity and heat consumption – beef cattle	Table 5	Sector publication	https://www.enerpedia.be/nieuws
Electricity and heat consumption – pig farms	Table 5	Sector publication	https://www.enerpedia.be/nieuws
Evolution of the electricity prices in Flanders	Figure 5	Sector publication	dashboard.vreg.be/report/DMR_Prijzen_elektriciteit.html
Electricity prices for households in Croatia from 2010 to 2020	Figure 6	Sector publication	Electricity prices for households 2021 S2 | Statista
Evolution of the price of natural gas	Figure 7	Sector publication	dashboard.vreg.be/report/DMR_Prijzen_gas.html
Main process parameters of a small-scale digester	Table 6	Sector publication	https://inagro.be/sites/default/files/media/files/2021-07/PocketPower_Onderzoeksrapport.pdf
Amount of manure produced per fattening pig and sow	Table 7	Legal Framework Flanders	https://www.vlm.be/nl/SiteCollectionDocuments/Publicaties/mestbank/Bemestingsnormen_2021.pdf
Amount of energy consumed per fattening pig and sow	Table 7	Legal Framework Flanders	https://www.vlm.be/nl/SiteCollectionDocuments/Publicaties/mestbank/Bemestingsnormen_2021.pdf
Costs per ton of pig manure produced in Flanders (costs per pig, costs per sow)	Table 8	Project produced data	D3.3

Costs per ton of pig manure produced in Croatia (costs per pig, costs per sow)	Table 9	Project produced data	D3.3
CBA assessment for the installation of a pocket digester - Subsidies	Table 10	Sector publication Legal framework	D2.6; https://www.biogas-e.be/sites/default/files/2020-12/PocketPower_Onderzoeksrapport_1.pdf
CBA assessment for the installation of a pocket digester– Cost disposal of manure and digestate	Table 10	Sector information (Assumption based on direct stakeholder interaction)	Direct interaction with stakeholders
CBA assessment for the installation of a pocket digester– Labour costs	Table 10	Sector information (Assumption based on direct stakeholder interaction)	Direct interaction with stakeholders
CBA assessment for the installation of a pocket digester – Repair & Maintenance	Table 10	Sector information (Assumption based on direct stakeholder interaction)	Direct interaction with stakeholders
CBA assessment for the installation of a pocket digester – investment	Table 10	Project produced data	D2.3
CBA assessment for the installation of a pocket digester– overall result (Pay back period)	Table 10	Project produced data	D3.3
CBA assessment with disposal of manure and digestate at an external treatment facility – evolution of energy costs	Table 11	Sector publication	https://dashboard.vreg.be/report/DMR_Prijzen_gas.html; https://dashboard.vreg.be/report/DMR_Prijzen_elektriciteit.html
CBA assessment with disposal of manure and digestate at an external treatment facility – impact of energy costs	Table 11	Project produced data	D3.3
CBA analysis for Flanders - disposal of digestate and manure on arable land	Table 12	Project produced data	D3.3
CBA analysis for Croatia - disposal of digestate manure on arable land	Table 13	Project produced data	D3.3

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

The principle of the adapted stable construction is that underneath the slatted floor of a stable system a shallow cellar is constructed which enables the immediate separation of urine and solid manure. Using a scraper, the solid manure is removed from the manure gutter daily. Thanks to this primary separation of manure in the cellar there is a lower ammonia production originating from the manure storage, what results in lower ammonia emissions. This latter is beneficial for both the ammonia emissions to the environment and the air quality inside the stable. The technique is independent of scale. Right now, there are approximately 15.000 places where this technique is being used.

In an adapted stable construction of VeDoWS (Vermeulen Dobbelaere Welfare System), pig manure is primarily separated into solid manure and urine.

Advantages:

- Primary separation of pig manure in the stable ensures a healthy environment for both the farmer and pigs due to reduced NH_3 and odour emissions.
- When calculating total costs, this technology would not be more expensive than a classic stable system (with grid floor) and an end-of-pipe technique (such as an air scrubber). As indicated in the deliverable D2.6 of the Nutri2Cycle project, the CAPEX is estimated at around 80-90 € per pig place (i.e. additional cost compared to a classic stable concept) and the yearly additional OPEX around 1.50 €. For the estimation of the economic impact on the farm, sector data were collected : where the disposal cost for non-separated manure is around 17.5 € per ton in Flanders. For the solid manure (40 % of total manure) of a VeDoWS system, the price is around 0-12 € per ton; for the urine (60 % of total manure) the price is around 5 € per ton (mostly transported to bring it on the field). The total disposal cost for manure of a VeDoWS stable should, therefore, be cheaper than non-separated manure.
- The cost per pig place is independent of scale, so there is no minimum economical industrial scale.
- There is no need for chemicals.

4.2.1 Background information

Low emission stables

Ammonia-emissions coming from agriculture are often regulated in regional or national legal frameworks. The sectors of piggery and poultry are known to have significant emissions from the stables. Mitigating measures can be imposed on existing stables, and new constructions/companies must meet stringent emission limits. In the region of Flanders only those stable-concepts that have received an accreditation as low-emission stable can be used. Since 2003, every pig- or poultry stable that was constructed in Flanders was obligated to use one of the accredited stable-concept. The obligation does not stand for cattle-production, nor for the farms with biological production.

The emission of a “low emission stable” will be at least 40 to 50 % lower than a regular stable. The accredited concepts are listed online and regularly updated. They are subdivided per animal-category. Also, the combination of different technologies (i.e. stable concept + air treatment) is included in these listings.

The Vedows-stable concept did receive the accreditation as a low-emission stable concept.

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

Regular manure processing

In a traditional stable, all the pig-manure is collected in a storage volume underneath the grid. The raw manure (slurry) is taken from this storage and either distributed on arable land or transported to an external manure treatment installation if not enough arable land is available.

Often the slurry (or at least part of it) is already separated at the farm site in a thick and a liquid fraction to lower the disposal costs as prices for treatment in a manure treatment facility will vary. It is also possible that either one of the fractions can be further treated on the farm – e.g. thick fraction could be composted (farm-scale composting), or the liquid fraction could be treated in a biological treatment plant.

One of the main benefits of the Vedows-system is that the thick and liquid fraction from the pig-manure are already separated from the start, what means that there is no need for an additional separation step.

Manure biogas potential

The Figure 8. shows the evolution of the biogas production potential of pig manure compared to the storage-time before being valorised for biogas production. It shows that the biogas production potential of "fresh" manure is significantly higher than the production potential of manure that has been stored for a certain period: fresh slurry would have a biogas potential of around 30 - 40 m^3/ton_{manure}, where once it is stored for more than 15 days, the biogas potential drops to below 15 - 20 m^3/ton_{manure}. When looking at the biogas potential of only the thick fraction of pig manure, the differences are even higher: fresh thick fraction can produce 90 – 110 m^3 biogas / ton_{manure}, but when being digested after 15 days of storage, it's production potential drops to 30 – 50 m^3 biogas / ton_{manure}.

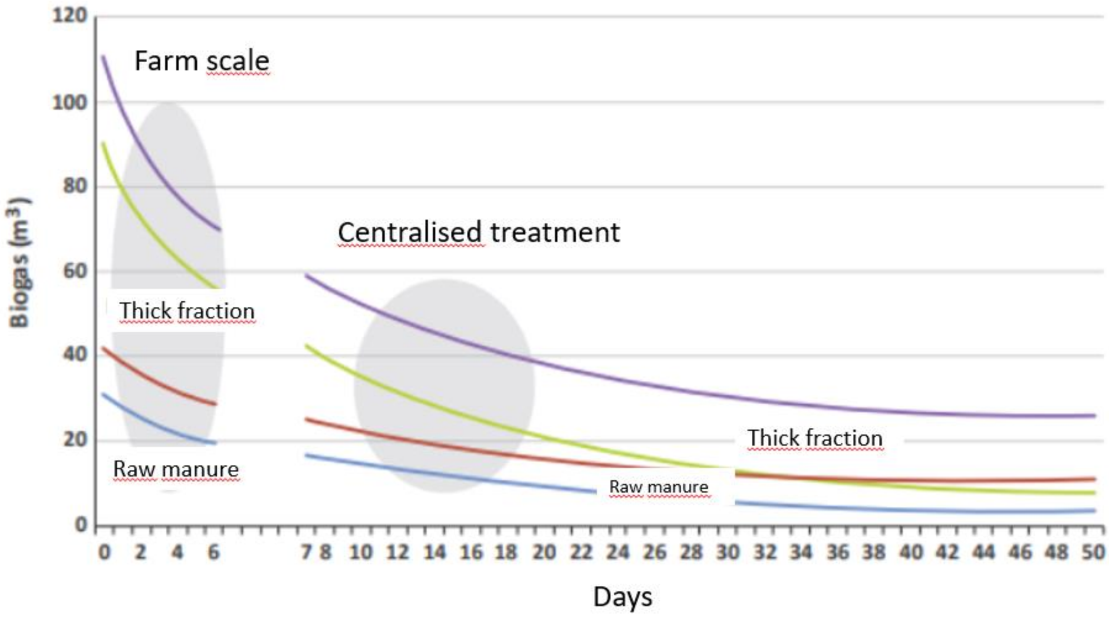

Figure 8. Evolution of the biogas potential from pig manure against days of storage, BLUE = Slurry min, RED = Slurry Max, YELLOW = Thick fraction min, PURPLE = thick fraction max (link)

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4.2.2 N2C case scenario

The scenario that will be evaluated is the use of the Vedows-concept when considering the construction of a new stable. The main benefits from the system are:

- Decreased emissions of greenhouse gases and NH_3 from manure storage
  - an additional air treatment (air washer) is not required anymore
  - lower impact on the environment and better health conditions for animals and the farmer
- Decreased odour emission
  - lower impact on the environment and better health conditions for animals and the farmer
- The manure has a higher biogas potential
- There is no need for an additional separation step
- The liquid fraction has a low P-concentration and can be considered a good NK fertilizer: no P limitations and fast released nutrients. It can be applied on land using regular machinery.

The table below shows the output of the manure, both for the classic stable concept (storage in cellar with afterwards the option of a separation step) and the Vedows concept.

Table 15. Composition of manure and manure derivated flows from a classic stable system and a Vedows-stable (link)

		Classic stable System			Vedows	
	Unit	Slurry	Thick fraction	Liquid fraction	Thick fraction	Liquid fraction
DM	%	8.15	25.6		24.5 – 26	
OC	%	5.85	21.1	4	112 – 122	7.86 – 10.92
N_{tot}	g/kg	5.6	10.5	4.8	9 – 12	3.28 – 3.7
P (P_2O_5)	g/kg	3.9	9.48	1	8.75 – 10.25	0.01 – 0.19
K (K_2O)	g/kg	5.25	7.14	3.9	6.5 - 8	

Within this CBA the evaluation of the installation of the Vedows-concept in a new stable will be done, as the reorganisation in existing stables is too complex (and expensive). As some of the benefits of the Vedows installation go beyond the mere stable, but also consist of the impact on the further handling of the manure, a comparison will be made between different scenarios:

- Scenario 1: Classic stable construction with air treatment & regular disposal of manure (no manure separation)
- Scenario 2: Classic stable construction with air treatment & small scale digester (monodigester)
- Scenario 3: Vedows system & regular disposal of manure
- Scenario 4: Vedows system & smale scale digester (monodigester)

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4.2.3 Financial/Economic analysis - Reference scenario

The reference scenario (= scenario 1 as indicated above) is a stable designed in a classic stable concept – i.e. the storage of the manure in a cellar under the grid. In Flanders this type of design implies for new stables to include an air treatment system as well. The total investment cost of this type of stable is around 400 €/m^2 in Flanders (data from the sector – 2021). Given that one pig place corresponds to 0.75 m^2, and that 1 pig corresponds to 1.5 ton manure/year it can be assumed that 1 m^2 of stable corresponds to the production of around 2 ton of manure per year.

For the exploitation in the reference scenario (Scen 1) the following costs will apply (for the treatment of manure both the options for disposal in an external treatment plant & disposal on arable land is given).

Table 16. Overview economic situation reference scenario

Cost per ton manure		Flanders (data 2021)	Croatia
Disposal of manure[1]	Slurry	17.5 €/ton (treatment) 4 €/ton (land)	- 10.5 €/ton
	Thick fraction	16 €/ton	- 40 €/ton
	Thin fraction	14 €/ton	0 €/ton
	Digestate	27.5 €/ton	- 10.5 €/ton
Air treatment[2]	Additives (water & chemicals)	1.3 €/ton	n.a.
	Energy	4.8 €/ton	n.a.
	Maintenance	1 €/ton	n.a.

The table above indicates a significant difference between the Flemish and the Croatian situation as in Croatia the costs for the disposal of manure or digestate is negative (it is an income), and the stables do not require air treatment systems to be installed.

Note: The costs as indicated above will have to be compensated by the income the farmer can generate from selling the pigs. These incomes are not taken into account in this CBA, as it is assumed that there is no significant difference between the number of pigs to be roared in a classic stable or a Vedows stable. Nevertheless, it must be emphasized that for the Vedows stable an additional benefit is that the climate in the stable will have a lower N-concentration, what will improve both the animals' and the farmer's health.

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[1] Data from the sector (2021)

[2] Data source : BREF (https://emis.vito.be/sites/emis/files/pages/3331/2017//BREF-intensieve_veeteelt_versie_2017.pdf – Table 4.142)

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4.2.4 Cost Benefit Analysis – Innovative scenario

Table 17. provides an overview of the cost benefit assessment of the 4 scenarios in Flanders. For this CBA the following assumptions were made:

- The separation step of scenario 2 is assumed to be a screw press;
- The small-scale digester in scenario 2 is designed in such a way that the overall electricity demand of the farm is covered. As during summertime no heat is consumed on the farm, only 40 kWh/ton manure can be consumed – the remaining heat will be destroyed (and will therefore not receive any green heat certificates (subsidies in Flanders). The savings that are made for heat and electricity also remain the same in scenario 4;
- In scenario 4 the excess green electricity is injected to the grid and sold as “grey electricity” for 0.067 €/kwe (Figure 5). It is assumed that the scenario with a classic stable and digester covers the net electricity request, so the surplus can be injected to the grid;
- The input to the digester in scenario 4 is 50% Vedows-thick fraction and 50% slurry as it is not possible to do mono-digestion on only thick fraction due to the high dry matter content. The biogas potential of this mixture is calculated to be around 67.5 m^3/ton (Vedows Thick fraction = 110 m^3/ton and slurry = 25 m^3/ton) (link);
- For the disposal of the slurry, thick fraction, thin fraction and digestate it is assumed that the costs will be similar and not taking into account the type of treatment at the farm. I.e. the costs as indicated in table 17 will be used;
- The operational costs for the Vedows system are taken from the data collected in deliverable 2.6 of the Nutri-2-Cycle project;
- The operational costs for the classic systems (i.e. separation step, air treatment) is taken from the data available in the European BREF on intensive livestock (tables 4.177; table 4.142) (link);
- No interest on possible financial loans is taken into account.

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

Table 17. CBA evaluation of the different scenarios for Flanders

Manure intensive region		Per Ton Manure		Scen 1	Scen 2	Scen 3	Scen 4
Technical	Stable system			Classic	Classic	Vedows	Vedows
	Manure treatment	Separation			Screw press	Vedows	Vedows
		Energy recovery			Digester		Digester
		Disposal		Disposal to treatment facility			
	Digester (technical)	Biogas production	m3/ton $_{manure}$		25		67,5
		Electricity production	kWe/ton $_{manure}$		35		94,5
		Heat production	kWth/ton $_{manure}$		75		202,5
	Subsidy	Grey electricity (injection to grid) (0,067 €/kWe)	€/ton $_{manure}$				3,99
		Heat Certificates (0,031 / kWth) only 40 kWth/ton manure consumed	€/ton $_{manure}$		1,2		1,2
		Green electricity certificates (0,067 / kWe)	€/ton $_{manure}$		2,3		6,3
	TOTAL BENEFITS		**€/ton $_{manure}$**	**0**	**3,59**	**0**	**11,56**
OPEX	Manure disposal	Slurry	ton /ton $_{manure\ input}$	1			
			€/ton $_{manure}$ (17,5 €/ton)	17,5			
		Thick fraction	ton /ton $_{manure\ input}$			0,4	
			€/ton $_{manure}$ (16 €/ton)			6,4	
		Thin fraction	ton /ton $_{manure\ input}$		0,8	0,6	0,6
			€/ton manure (14 €/ton)		11,2	8,4	8,4
		Digestate	ton /ton $_{manure\ input}$		0,2		0,4
			€/ton $_{manure}$ (27,5 €/ton)		5,5		11
		Total disposal costs	**€/ton $_{manure}$**	**17,5**	**16,7**	**14,8**	**19,4**
	Energy	Electricity	€/ton $_{manure}$	7,8		7,8	
		Heating	€/ton $_{manure}$	5,5		5,5	
		Total energy costs	**€/ton $_{manure}$**	**13,3**		**13,3**	
	Air Treatment	Additives (water / chemicals)	€/ton $_{manure}$	1,3	1,3		
		Energy	kWh$_e$/year.ton$_{manure}$	20	20		
			€/ton $_{manure}$ (0,24 €/kWh$_e$)	4,8	4,8		
		Maintenance	€/ton $_{manure}$	1	1		
		Total costs air treatment	**€/ton $_{manure}$**	**7,1**	**7,1**		
	Separation system	Energy	kWh$_e$/year.ton$_{manure}$		1	0,55	0,55
			€/ton $_{manure}$ (0,24 €/kWh$_e$)		0,24	0,132	0,132
		Maintenance	€/ton $_{manure}$		0,3	1	1
		Total costs Manure separation	**€/ton $_{manure}$**		**0,54**	**1,132**	**1,132**
	Digester	Labour	€/ton $_{manure}$		0,5		0,5
		Repair & Maintenance	€/ton $_{manure}$		1,8		1,8
		Total costs digester	**€/ton $_{manure}$**		**2,3**		**2,3**
	TOTAL COSTS		**€/ton $_{manure}$**	**37,9**	**26,64**	**29,232**	**22,832**
	Yearly balance (Benefits - costs)		**€/ton $_{manure}$**	**-37,9**	**-23,06**	**-29,232**	**-11,27**
		impact of investment (comparison to scen 1)	**€/ton $_{manure}$**		**14,85**	**8,668**	**26,63**
Investment	Stable system	Total investment (incl. air treatment in the classic system)	€/pig place	400	400	490	490
			€/ton	266,7	266,7	326,7	326,7
		Annualised investment costs (15 year; 1,5 ton manure /pig place.year)	€/ton.year	17,8	17,8	21,8	21,8
	Separation system	Total investment	€		30000		
			€/ton		6		
		Annualised investment costs (8 year; 5000 ton/yr)	€/ton.year		0,75		
	Small scale digester	Total investment	€		175000		225000
			€/ton		35		45
		Annualised investment cost (8 year)	€/ton.year		4,38		5,63
	TOTAL INVESTMENT COST		€/ton	266,67	307,67	326,67	371,67
		impact of investment (comparison to scen 1)	€/ton		41,00	60,00	105,00
			€/ton $_{manure}$.year	**17,8**	**22,9**	**21,8**	**27,4**
		impact of investment (comparison to scen 1)	**€/ton $_{manure}$.year**		**5,1**	**4,0**	**9,6**
	Overall comparison to scenario 1		**€/ton manure.year**		**9,72**	**4,67**	**17,00**
		Period to equal classic system (scen 1)	**year**		**2,76**	**6,92**	**3,94**

The following results can be deducted from Table 17:

- An additional income is generated when installing a digester (certificate system) what makes that the Benefits in the scenario's with a digester a higher : +3.59 €/ton$_{manure}$ for a classic stable, and +11.56 €/ton$_{manure}$ for a Vedows stable system;
- On the matter of the operational costs, the highest operational costs are in the situation of a classic stable without a digester (37.9 €/ton$_{manure}$). When investing in a small scale digester after a classic stable, the costs will go down to around 26.6 €/ton$_{manure}$. In case one would not invest in a classic, but in a Vedows-type of stable, the yearly operational cost would be around 29.2 €/ton$_{manure}$. If the Vedows-stable would be combined with a small scale digester, it would even go down to 22.8 €/ton$_{manure}$;

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- When considering those yearly costs and benefits, it shows that – when comparing to the situation of a mere classic stable – the economic benefit on a yearly balance is that of the Vedows-system combined with a small scale digester (an economic benefit of 26.63 €/ton.$_{manure}$ every year). It also shows that the economic benefit of the Vedows-stable system without the digester (i.e. a benefit of 8.67 €/ton$_{manure}$ per year) is lower than the economic benefit of the installation of a digester after a classic stable (i.e. a benefit of 14.85 €/ton$_{manure}$ per year);
- The investment costs are the lowest for the classic stable construction, and the highest for the Vedows stable in combination with a small scale digester. In orde to be able to do the economic evaluation, the investment costs have been annualised over a period of 8 year. This shows that the investment cost for the Vedows in combination with a digester is about 9.6 €/ton$_{manure}$ more expensive per year than a classic stable system. The investment of the Vedows stable (without digester) of a small scale digester after a classic stable lay in the same order of magnitude (i.e. respectively 4.0 €/ton$_{manure}$ per year and 5.1 €/ton$_{manure}$ per year more than the classic stable system).
- When combining the above (operational costs, operational benefits and investment costs) the evaluation shows that when comparing to the investment of a classic stable construction, the additional investment in a small scale digester should be recovered in around 2.8 year. When investing in a Vedows stable without a digester, one would need almost 7 years to recover the higher investment in the stable. And when doing the maximal investment of a Vedows-stable in combination with a digester, the time to recover the additional investment would still be around 4 years.

An important conclusion that can be drawn from this assessment is that the system with the highest economic win on the yearly balance (i.e. the system of the Vedows stable in combination with a small scale digester with a yearly profit of around 26 €/ton$_{manure}$) is in the end **not** the solution with the highest ecomic value. The best resulting scenario is that of the classic stable with a small scale digester, and not the Vedows-stable system.

A similar assessment was done for Croatia (Table 18). The main differences between the situation in Croatia (compared to Flanders) are the lower investment cost (thanks to a 70 % subsidy system) and the lower disposal costs.

The results of this assessment are summarised in the table below. It shows that where the benefits are more or less equal between all the different scenarios, there is a difference in the yearly operational costs. Due to the fact that the disposal of the thin fraction does not result in an income for the farmer makes that the concept in which the classic stable is combined with a small scale digester results in higher operational costs. For the situation of the Vedows system in combination with a digester the impact is close to zero. If the farmer would invest in a Vedows stable, he could lower the yearly costs with about 4.4 €/ton$_{manure}$ per year.

When taking into account the investments needed, it shows that for the situation of a manure extensive region the investment in neither one of the 3 offered solutions is really economically viable. The most interesting solution is the choice of a Vedows system, though it also needs a period of 13.5 years to recover the higher investment costs.

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Table 18. CBA evaluation of the different scenarios for Croatia

Manure extensive region		Per Ton Manure		Scen 1	Scen 2	Scen 3	Scen 4
Technical	Stable system			Classic	Classic	Vedows	Vedows
	Manure treatment	Separation			Screw press	Vedows	Vedows
		Energy recovery			Digester		Digester
		Disposal		Disposal to treatment facility			
	Digester (technical)	Biogas production	m3/ton$_{manure}$		25		67,5
		Electricity production	kWe/ton$_{manure}$		35		94,5
		Heat production	kWth/ton$_{manure}$		75		202,5
	Subsidy	Grey electricity (injection to grid) (0,037 €/kWe)	€/ton$_{manure}$				2,19
		Heat Certificates (0,031 / kWth) only 40 kWth/ton manure consumed	€/ton$_{manure}$				
		Green electricity certificates (0,067 / kWe)	€/ton$_{manure}$				
	TOTAL BENEFITS		**€/ton$_{manure}$**	**0**	**0,00**	**0**	**2,19**
OPEX	Manure disposal	Slurry	ton /ton$_{manure\ input}$	1			
			€/ton$_{manure}$ (-10,5 €/ton)	-10,5			
		Thick fraction	ton /ton$_{manure\ input}$			0,4	
			€/ton$_{manure}$ (-40€/ton)			-16	
		Thin fraction	ton /ton$_{manure\ input}$		0,8	0,6	0,6
			€/ton manure (0 €/ton)		0	0	0
		Digestate	ton /ton$_{manure\ input}$		0,2		0,4
			€/ton$_{manure}$ (-10,5 €/ton)		-2,1		-4,2
		Total disposal costs	**€/ton$_{manure}$**	**-10,5**	**-2,1**	**-16**	**-4,2**
	Energy	Electricity	€/ton$_{manure}$	4,28		4,28	
		Heating	€/ton$_{manure}$	3,04		3,04	
		Total energy costs	**€/ton$_{manure}$**	**7,32**		**7,32**	
	Air Treatment	Additives (water / chemicals)	€/ton$_{manure}$				
		Energy	kWh$_e$/year.ton$_{manure}$				
			€/ton$_{manure}$ (0,132 €/kWh$_e$)				
		Maintenance	€/ton$_{manure}$				
		Total costs air treatment	**€/ton$_{manure}$**				
	Separation system	Energy	kWh$_e$/year.ton$_{manure}$		1	0,6	0,6
			€/ton$_{manure}$ (0,132 €/kWh$_e$)		0,132	0,1	0,1
		Maintenance	€/ton$_{manure}$		0,3	1,0	1,0
		Total costs Manure separation	**€/ton$_{manure}$**		**0,432**	**1,1**	**1,1**
	Digester	Labour	€/ton$_{manure}$		0,25		0,25
		Repair & Maintenance	€/ton$_{manure}$		1,8		1,8
		Total costs digester	**€/ton$_{manure}$**		**2,05**		**2,05**
	TOTAL COSTS		**€/ton$_{manure}$**	**-3,18**	**0,4**	**-7,6**	**-1,1**
	Yearly balance (Benefits - costs)		**€/ton$_{manure}$**	**3,18**	**-0,4**	**7,6**	**3,3**
		impact of investment (comparison to scen 1)	**€/ton$_{manure}$**		**-3,6**	**4,4**	**0,1**
Investment	Stable system	Total investment (no air treatment in the classic system)	€/pig place	350	350	440	440
			€/ton	233,3	233,3	293,3	293,3
		Annualised investment costs (15 year; 1,5 ton manure /pig place.year)	€/ton.year	15,6	15,6	19,6	19,6
	Separation system	Total investment	€		30000		
			€/ton		6		
		Annualised investment costs (8 year; 5000 ton/yr)	€/ton.year		0,75		
	Small scale digester	Total investment	€		52500		67500
			€/ton		10,5		13,5
		Annualised investment cost (8 year)	€/ton.year		1,31		1,69
	TOTAL INVESTMENT COST		€/ton	233,33	249,83	293,33	306,83
		impact of investment (comparison to scen 1)	€/ton		16,50	60,00	73,50
			€/ton$_{manure}$.year	**15,6**	**17,6**	**19,6**	**21,2**
		impact of investment (comparison to scen 1)	**€/ton$_{manure}$.year**		**2,1**	**4,0**	**5,7**
	Overall comparison to scenario 1		**€/ton manure.year**		**-5,62**	**0,43**	**-5,59**
		Period to equal classic system (scen 1)	**year**		**-4,64**	**13,55**	**784,8**

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4.2.5 Comparative analysis of innovative scenario and published research

Adapted stable construction presented within the technology LL24, showcases a promising solution for efficient manure management, specifically focusing on the immediate separation of urine and solid manure beneath a slatted floor. This innovative design leads to a notable reduction in ammonia production, resulting in lower overall ammonia emissions during manure storage. The economic viability of this technology is evident in the cost analysis, revealing that the adapted stable system is comparable in expenses to traditional stable systems (with a grid floor) and end-of-pipe techniques like air scrubbers.

The CAPEX for this technology is estimated at around 80-90 € per pig place, representing an additional cost compared to a conventional stable concept. Moreover, the yearly OPEX is estimated to be around 1.50 € per pig place. Crucially, the disposal cost for manure from the adapted stable construction is highlighted as being considerably lower in Flanders than that of non-separated manure, making it an economically attractive option. Specifically, the disposal cost for solid manure (40 % of total manure) ranges from 0-12 € per ton, while for urine (60 % of total manure), the cost is around 5 € per ton, mostly for transportation to agricultural fields.

Within the project of Pocket Power also the input of manure from the Vedows system was considered (link). The outcome of those results can be considered comparable to the economic evaluation of the Scenario 4, though it does not consider the evaluation of the investment costs in the stable construction itself.

The technology of the Vedows system was also considered in the Nutriman project, though this did not include an economic evaluation.

In summary, the adapted stable construction offers an economically competitive and environmentally acceptable solution, especially when compared to traditional methods, while the dairy production approach, while effective in certain aspects, presents challenges in achieving a complete gas reduction.

4.2.6 Conclusions

For a manure intensive region it can be concluded that the reference scenario in which there is just a classic stable without the further processing and digestion of the manure is the least favourable situation. All other scenarios result in a positive overall impact per ton manure. The most favourable scenario though is the situation in which the manure is treated in a separation system (screw press) and then further digested. The additional investments for scenario 2 compared to the reference situation are regained within 3 years' time. Also the investment in a Vedows system combined with a digester is to be considered as economically viable, as the payback period is only 3.7 years. Investing in the Vedows system without the benefit of digesting the manure seems to be less economically viable, given that the payback period increases up to almost 7 years.

For a manure extensive region the results are completely different: as the manure (or digestate) as whole can generate an income, the use of the thin fraction is assumed not to create an income. This has an immense impact on the economic feasibility, resulting in the conclusion that the only economically viable solution here is to work with a classic stable system. In case a market value could be created for the liquid fraction of digestate the economic viability will change significantly.

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Table 19. Overview of data used as reference to CBA study

Data	**Reference CBA Study**	**Type of data**	**Source of data**
Composition of manure and manure derivated flows - Classic stable System	Table 15	Sector / legal publication	vlm.be
Composition of manure and manure derivated flows - Vedows	Table 15	Sector / legal publication	vlm.be
Cost per ton manure – disposal of manure, Flanders	Table 16 Table 17 Table 18	Sector information (Assumption based on direct stakeholder interaction)	Data from the sector (2021)
Cost per ton manure – air treatment, Flanders	Table 16 Table 17 Table 18	Sector publication	https://emis.vito.be/sites/emis/files/pages/3331/2017/BREF-intensieve_veeteelt_versie_2017.pdf
Biogas production rate	Table 17 & 18	Project Produced Data	D3.3
Electricity production rate	Table 17 & 18	Project Produced Data	D3.3
Heat production rate	Table 17 & 18	Project Produced Data	D3.3
Energy costs (heat and electricity)	Table 17 & 18	Sector publication	https://dashboard.vreg.be/report/DMR_Prijzen_gas.html; https://dashboard.vreg.be/report/DMR_Prijzen_elektriciteit.html; Electricity prices for households 2021 S2 | Statista
Maintenance costs	Table 17 & 18	Sector information (Assumption based on direct stakeholder interaction)	Data from the sector (2021)
Labour costs	Table 17 & 18	Sector information (Assumption based on direct stakeholder interaction)	Data from the sector (2021)
Investment costs	Table 17 & 18	Project Produced data	D2.6

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5. Research Line 2: Innovative soil, fertilisation & crop management systems & practices (#LL 16 and #LL 17)

5.1 LL16 Farm using digestate, precision agriculture and no-tillage focusing on OM stocking in an area characterized by the lack of OM

This solution is a complex synergy of technologies to process wastewaters, OFMSW, and agro/food industrial wastes. It includes AD, an ammonia stripping system, bio-fertilizer and soil enhancer production, precision farming, and minimum tillage tools to effectively run rice-culture.

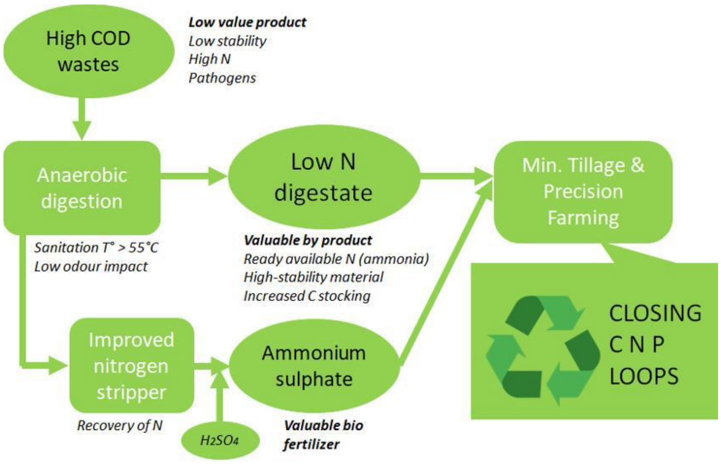

Figure 9. Technology concept

Field trials were set up in collaboration with an anaerobic digestion demo plant in Lombardia. Two crops were considered (rice and wheat). The AD plant under study treats about 70.000 t/year^{-1} of wastes (mainly sewage sludge of urban wastewater) producing digestate, exploited as amendment and fertilizer on the field, and biogas. The digestion phase takes place at 55 °C for at least 20 days, through a set of 3 reactor tanks in sequence, so that the effluent is hygienically safe and with a low odour impact. Furthermore, digestate nitrogen is found mainly in ammonia form, which is the most easily absorbed by plants. Ammonia is a well-known inhibitor of anaerobic digestion, but the stripping system allows a higher yield of biomethane.

The efficiency of this highly valuable effluent is increased by precision farming and minimum tillage tools. These techniques can reduce the waste of nutrients and the loss of organic matter to increase the stocking of carbon and, together with the production of biogas, close the carbon cycle. Currently, this technique is applied in Acqua & Sole organization, sited in Vellezzo Bellini, PV, Italy.

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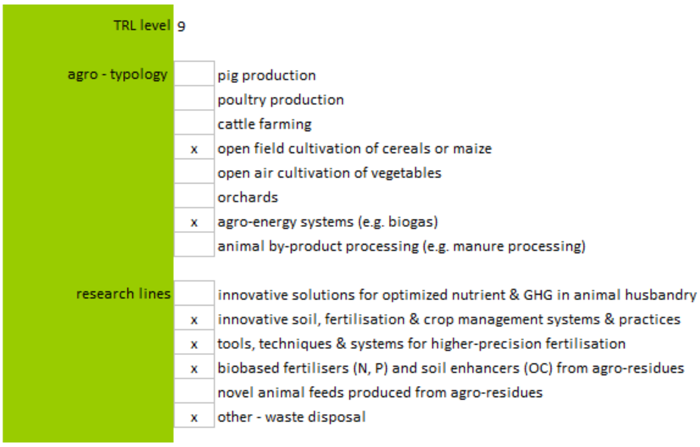

TRL level	9	
agro - typology		pig production
		poultry production
		cattle farming
	x	open field cultivation of cereals or maize
		open air cultivation of vegetables
		orchards
	x	agro-energy systems (e.g. biogas)
		animal by-product processing (e.g. manure processing)
research lines		innovative solutions for optimized nutrient & GHG in animal husbandry
	x	innovative soil, fertilisation & crop management systems & practices
	x	tools, techniques & systems for higher-precision fertilisation
	x	biobased fertilisers (N, P) and soil enhancers (OC) from agro-residues
		novel animal feeds produced from agro-residues
	x	other - waste disposal

Figure 10. LL16 Technology TRL, agro-typology and research lines

5.1.1 Background information

Organic matter in the soil

Soil organic matter is extremely important in all soil processes. It is essentially derived from residual plant and animal material, synthesized by microbes, and decomposed under the influence of temperature, moisture, and ambient soil conditions (link). High content of organic matter in the soil is not just responsible for ensuring stable crop production but also for maintaining the soil in a good condition. Structure, water capacity, pH, soil microorganism, drainage, and other parameters of the soil are conditioned by the content of organic matter.

Soil carbon stocks in the EU-27 are around 75 billion tonnes of carbon, around 50 % of which is in Ireland, Finland, Sweden, and the United Kingdom. Around 45 % of the mineral soils in Europe have low or very low organic carbon content (0-2 %) and 45 % have a medium content (2-6 %) (link). Low levels are particularly evident in southern Europe where 74 % of the land is covered by soils that have less than 2 % carbon in the topsoil (link). However, areas of low organic carbon can be found almost everywhere, including in some parts of more northern countries such as Belgium, France, Norway, Germany, and the United Kingdom (link). In Croatia, the percentage of soil organic matter is 2.97 % in total agricultural land, in arable land (cereals and vegetables) the percentage is 2.57 %, while the largest share is in orchards (4.45 %) (link).

No-tillage

No-tillage is a minimum tillage practice in which the crop is sown directly into the soil without tilling since the harvest of the previous crop (link). The main advantages of no-tillage are fuel and labour savings, reduced soil erosion, reduced herbicide runoff, moisture conservation, trapped carbon, higher yields, improved soil biology, and reduced compaction. In addition to the advantages, there are disadvantages such as upfront costs, weed problems and reliance on herbicide, changes in the weed spectrum, insects, longer-term crop rotation plans, and nutrient stratification (link).

Precision agriculture

Precision agriculture means that crops precisely get the treatment they need, determined with great accuracy thanks to the latest technology. The big difference with classical agriculture is that rather than determining the necessary action for each field, precision agriculture allows actions to be determined per square meter or even per plant (link).

Wheat production

Wheat is cultivated on about 50 % of cropland in the EU. On a global scale, Europe accounts for 20 % of the total cereal production. Wheat is used almost equally for animal feed and human consumption.

The European grain trade organization Coceral estimates the production of common wheat in the 27 EU Member States in 2022 at 125.4 million tons (link).

In 2020, wheat production for Belgium was 1.74 million thousand tonnes (link). In 2019, wheat was cultivated on 138.000 hectares in Croatia, of which 45.000 were in Osijek-Baranja County (link).

Fertilization of wheat may include the application of mineral fertilizers and the application of new forms of fertilizers. In Croatia, the recommended fertilization product for wheat is NPK 7-20-30 in the amount of 350 kg/ha. In pre-sowing fertilization, it is recommended to use 80 kg/ha UREA or 300 kg/ha CAN, while for supplementation the recommended fertilizer is NPK 15-15-15 in the amount of 125 kg/ha. Sources in Belgium advise that fertilization with P and K is most of the time not necessary, but the recommended N/ha brought on wheat parcels is between 176 – 225 kg N/ha depending on the present N in the soil (link).

Digestate

Digestate is a nutrient-rich substance produced by anaerobic digestion that can be used as a fertiliser. Liquid digestate is an alternative to bagged fertiliser and some of the benefits foreseen are reduction in costs of fertiliser, more readily available source of nitrogen, reduction of business carbon footprint, and provision of C, N, P, and trace elements. Solid digestate can be used as a soil conditioner and its benefits include increasing soil moisture retention and therefore available water capacity, providing a valuable source of organic matter in the soil, improving drainage (link). Organic fertilisers in the form of digestate offer an excellent alternative compared with energy-intensive mineral fertilisers, as they release very low (or even) neutral GHG emission values throughout their full production cycle (link).

5.1.2 N2C case scenario

The N2C case scenario is a complex synergy of technologies to process wastewaters, OFMSW, and agro-food industrial wastes. It includes AD, ammonia stripping system, bio-fertilizer, and soils enhancers production, nutrients recycling, precision farming, and minimum tillage tools to effectively run rice-culture.

Table 20. indicates the most important parameters of the case scenario, including information on waste streams used and products obtained as well as digestate application rates used and soil characteristics on the site.

Table 20. Overview of N2C case scenario

Waste input	5000-6000 Ton/month Mainly municipal sewage sludge DM 19 % Total Organic C: 351 g/kg Total N: 54 g/kg P: 19 g/kg
Main product	Digestate DM 10.3 % Total Nitrogen 77 g/kg Total organic Carbon 31 Characteristics: 4g/kg Total P 28 g/kg
By-products	50 Ton/month Ammonium sulphate 7.2 % NH4-N
Crop rotation	No rotation
Fertilisation management	Potassium chloride is added in pre-sowing with digestate

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Application of products from innovative technology	Digestate is injected on minimum tillage, while ammonium sulphate is given on top
Application rates	Digestate 30,000 kg/ha Ammonium sulphate 10.000 kg/ha
Nutrient concentrations in digestates, manure	DM 10.3 % Total Nitrogen 77 g/kg Total organic Carbon 314 g/kg Total P 28 g/kg
Soil properties	SOM: 1.8 % P Olsen: 24 mg/kg pH 5.7 TN 1.2 g/kg
Saving rates for fertilizers such as the substitution of min. fertilizer with manure	Urea 150 kg/ha/y KCl 80 kg/ha/y

The field trials were set up in collaboration with an AD demo plant in Lombardia (northern Italy) to investigate the effect of the combined use of digestate, precision agriculture and no-tillage in a real farming system. Two crops, rice, and wheat were considered. The AD plant under study treats about 70.000 t/year of waste (mainly sewage sludge of urban wastewater) producing digestate, exploited as an amendment and fertilizer infield, and biogas.

The innovative solution consists of a stripping system pared with an AD plant. This system decreases the Total Ammonia Nitrogen (TAN) level in the reactor, avoiding or reducing ammonia inhibition during the AD, while at the same time producing ammonium sulphate $(NH_4)_2 SO_4$, which is mainly exploited as a valuable fertilizer in the field.

Experimental rice and wheat fields are disposed of close to the AD plant, covering an overall area of 2 ha. They are divided into 9 parcels of around 600 m^2, where 3 types of treatments (digestate fertilization, mineral fertilization, and a non-fertilized control) are tested in triplicate. During agricultural season ammonia emissions were measured, as well as nitrous oxide, methane, and carbon dioxide emissions. For each trial of each culture, the soil is characterized in 5 sampling times distributed during the agricultural season.

The soil profile is characterized in terms of nitrogen speciation, soil texture, water content, temperature, pH, ORP, TOC, Assimilable Phosphorus.

All characteristics of digestate and ammonium sulphate fit the legal limits for their use on the field as fertilizers. The C/N ratio of wastes used in the digester was quite low compared to literature, though the yield of biogas was excellent, thanks, probably to the stripping system that reduces free ammonia in the reactors. Data collected till now have demonstrated that odour emissions during soil application of digestate are like those from mineral fertilizer, when digestate injection in the soil is used as an application technique, instead of traditional spreading on the soil surface.

Ammonia emissions were higher in plots treated with mineral fertilization, and lower in plots fertilized with digestate. Parcels fertilized with digestate also showed lower cumulative emissions of N_2O and higher cumulative emissions of CH_4, compared with treatments with mineral fertilization; carbon dioxide emissions seem to be not influenced by the type of fertilization.

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Data collected so far shows that rice yields are not statistically different between treatments. Concerning nitrate leaching, results show that there is a possible risk for this phenomenon only after fertilization; however, nitrate concentrations in deeper layers of soil profile were very low (< 20 mg/kg), with no differences between digestate and mineral fertilization.

5.1.3 Financial/economic analysis – Reference scenario

The reference scenario implies to:

- Production of wheat under standard conditions which implies the use of mineral fertilizers, pesticides, and agricultural mechanization;
- Soil cultivation;
- Agrotechnical measures include distribution of mineral fertilizers, ploughing, rotary harrowing, sowing, spraying, transport.

Balance (gross margin) calculations of wheat production in standard conditions, as well as the effect of price and balance on variable cost calculations for Croatia and Flanders in 2019 and finally the recommended fertilization plan for Croatia in 2019, is indicated in the following tables.

Table 21. Balance calculations for wheat production in Croatia and Belgium (2019)

Reference scenario (Wheat)			**Croatia (2019)**	**Flanders (2019)**
Benefits	Yield	kg/ha	6000	9549
	Unit price	€/ton	140	185
	Total income	**€/ha**	**840**	**1766,57**
Production costs	Seed	€/ha	100,12	101
	Mineral fertilizers	€/ha	291,53	151
	Pesticides	€/ha	131,69	235
	Energy	€/ha	95	95
	Other costs (insurance, redemption, …)	€/ha	78,59	93
	Total production costs	**€/ha**	**601,92**	**675**
Mechanization costs	Rented mechanization	€/ha	80,74	177
	Own mechanization	€/ha	111,21	84
	Rent land	€/ha	-	300
	Cost of contract work	€/ha	-	230
	Total harvesting costs	**€/ha**	**191,95**	**791**
TOTAL COSTS		**€/ha**	**793,87**	**1466**
Gross Margin Calculation (GMC)		€/ha	46,13	300,57

Table 22. Effect of wheat price and gross margin calculation (GMC) on variable cost calculations in Croatia and Belgium (Flanders)

WHEAT	**Unit price (€/kg)**		**Gross margin calculation (€/ha)** (no machinery costs)		**Gross margin calculation (€/ha)** (including machinery cost)	
	CROATIA	**FLANDERS**	**CROATIA**	**FLANDERS**	**CROATIA**	**FLANDERS**
Extreme - low	-	0,14	-	661,86	-	-129,14
lower price	0,13	0,174	178,08	986,53	-13,87	195,53
average price	0,14	0,185	238,08	1.091,57	46,13	300,57

higher price	0,16	0,196	358,08	1.196,60	166,13	405,60
Extreme - high	-	0,24	-	1.616,76	-	825,76

Gross margin calculation (GMC) is based on the determination of income and variable costs of production in the production season and/or calendar year. The structure of income in the calculations includes all revenues generated from the sale of products and other revenues generated in a particular production, which can be directly linked to production resource unit (support per ha/LU). The amount of income depends on the quantity of the manufactured product as well as the number of sold pieces and their price. When all the cost of renting machinery and/or the cost of own machinery are included in the calculation of the GMC, gross margin calculation obtains all costs.

The data of the advisory service of the Ministry of Agriculture and the prices stated in the market information system (TISUP) were used as a source and a reference of prices for the gross margin calculation for Croatia.

Table 23. Recommended fertilization plan for standard wheat production in Croatia (2019) (link)

Recommended fertilization Wheat (Croatia 2019)					Applied fertilizers / ha				**Fertilizer costs**
Type of fertilizer	Kg N / kg	kg P2O5 / kg	kg K2O / kg	€/kg	**Total kg fertilizers**	**N**	**P2O5**	**K2O**	**€/ha**
CAN	0.27			0,21	**300**	81			**63**
UREA	0.46			0,29	**80**	37			**23,2**
NPK	0.15	0.15	0.15	0,32	**125**	19	19	19	**40**
NPK	0.07	0.20	0.30	0,47	**350**	25	70	105	**164,5**
Total					**855**	**162**	**89**	**124**	**290,7**

Recommended fertilization plan for standard wheat production in Croatia is shown in Table 23.

The lowest price of wheat in 2019 for Croatia was 0,13 €, the highest 0,16 €, and the average price of wheat was 0,14 €/kg. The lowest price of wheat in Belgium in 2020 was 0,18 €, the highest price was 0,20 €, while the average price was 0,19 €/kg. In 2021, the average price of wheat was higher than in 2019, and it amounted to 0,24 €/kg.

Over the mentioned period, there is a noticeable variation in wheat prices between Croatia and Belgium. Additionally, there is an upward trend in the average wheat prices in Belgium from 2019 to 2021.

5.1.4 Cost-benefit analysis – Innovative scenario

Production of wheat in innovative conditions implies to:

No-tillage method;
Precision agriculture where crops precisely get the treatment they need, determined with great accuracy thanks to the latest technology;
Use of digestate and GPS geolocator for accurately dosing.

Balance (gross margin) calculations of wheat production in innovative scenario, as well as the effect of price and balance on variable cost calculations for Croatia and Flanders in 2019 and finally the recommended fertilization plan is indicated in the following tables. Balance calculations included assumption of 20 % higher price of the pesticides then in reference scenario, as in no-till systems there are mostly increased herbicide costs. Information used for preparation of scenarios were also covered through the input of Deliverable 2.6. While the expected yield is projected to remain constant, it's important to note that actual outcomes may deviate from this prediction.

Table 24. Balance calculations for wheat production in Croatia and Belgium if using innovative scenario

Innovative scenario (Wheat)			Croatia (2019)	Flanders (2019)
Benefits	Yield	kg/ha	6000	9549
	Unit price	€/ton	140	185
	Total income	**€/ha**	**840**	**1766,57**
Production costs	Seed	€/ha	100,12	101
	Pesticides	€/ha	158.03	282
	GPS geolocator	€/ha	400	400
	Digestate	€/ha	58,80	-
	Energy	€/ha	95	95
	Other costs (insurance, redemption, …)	€/ha	78,59	93
	Total production costs	**€/ha**	**890.54**	**971**
Mechanization costs	No-tillage system	€/ha	0,00	0,00
	Rented mechanization	€/ha	80,74	177
	Own mechanization	€/ha	111,21	84
	Land rent	€/ha	-	300
	Total harvesting costs	**€/ha**	**191,95**	**561**
TOTAL COSTS		**€/ha**	**1.082,49**	**1.532**
Gross Margin Calculation (GMC)		€/ha	-242,49	234,57

Table 25. Effect of wheat price and gross margin calculation on variable cost calculations in innovative cases, if applied in Croatia and Belgium (2019)

WHEAT	**Unit price (€/kg)**		**Gross margin calculation (€/ha)** (no machinery costs)		**Gross margin calculation (€/ha)** (including machinery cost)	
	CROATIA	**FLANDERS**	**CROATIA**	**FLANDERS**	**CROATIA**	**FLANDERS**
Extreme - low	-	-	-	-	-	-
lower price	0,13	0,174	-110.54	690,52	-302,49	129,53
average price	0,14	0,185	-50,54	795,57	-242,49	234,57
higher price	0,16	0,196	69.46	900,60	-122,49	339.60
Extreme - high		-	-	--	-	-

Table 26. Recommended fertilization plan if digestate from the innovative case is being used (2019) (link)

Recommended fertilization plan	kg	N	**P_2O_5**	**K_2O**	**Fertilizer costs (€/t)**
Digestate (77 g/kg TN, 28 g/kg P)	1.575	162	58,8	-	58,80
Ammonium sulphate (7,2 % NH4-N)	525	40,50	-	-	30 €/m^3

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Table 27. Amounts of total organic carbon added by recommended fertilization plan for digestate

	Amount (kg)
Amount of digestate recommended for fertilization (kg/ha)	1.575 kg
DM (10.3 %)	166,3 kg
Total organic carbon (314 g/kg)	494,55 kg

By adding 1.575 kg of digestate that has DM of 10.3 %, the TOC amount added to soil is 494,55 kg. A hectare of soil that contains 2,57 % of organic matter will see an increase of 0,0024 % in organic matter content due to addition of the amount of total organic carbon from digestate.

5.1.5 Comparative analysis of innovative scenario and published research

Within the project, an anaerobic digestion (AD) demo plant in Lombardia, northern Italy, explored the combined impact of digestate, precision agriculture, and no-tillage in a practical farming system. The AD plant processed approximately 70,000 tons/year of waste, predominantly sewage sludge from urban wastewater, producing digestate used as an amendment and fertilizer in the field, as well as biogas. The innovative approach involved a stripping system paired with the AD plant, effectively reducing Total Ammonia Nitrogen (TAN) levels in the reactor to prevent or minimize ammonia inhibition during the AD process. Additionally, the system produced ammonium sulphate $(NH4)2\ SO4$, a valuable fertilizer used in the field.

One of the founded studies focused on assessing the economic advantages of precision agriculture in six case study farms within the Australian wheatbelt. These farms represented diverse agro-climatic regions, cropping systems, farm sizes, soil types, and production levels. Farmers, engaged in precision agriculture for 2 to 10 years, utilized various technologies such as guidance, variable rate fertilization, auto-steer, tramlining, NDVI, and GreenSeeker for nitrogen management. Standard economic analyses, including gross margin calculations and discounted cash flow analysis, were applied. Capital investment in precision agriculture ranged from $55,000 to $189,000, with recovery typically within 2-5 years. Annual benefits varied from $14 to $30 per hectare, with quantifiable benefits observed in variable rate fertilization ranging from $1 to $22 per hectare. Paddock-specific benefits ranged from -$28 to +$57 per hectare per year (link).

A one-year field experiment in Southern Italy investigated soil fertility under different tillage practices in two tree orchards. The study compared conventional tillage, conventional tillage combined with the incorporation of solid anaerobic digestate, and no-tillage. The results indicated that soil aggregate stability remained unaffected under no-tillage and improved with the addition of digestate in two distinct soil textures (clay and sandy loam). In the fine-textured soil, there was a significant and enduring increase in the organic pool, microbial C-use efficiency, and release of soluble C and N forms. However, in moderately coarse alkaline soil, digestate use did not yield beneficial effects on the soil organic pool and even stimulated the depletion of C resources, microbial respiration, and N losses due to NH4 volatilization. The study emphasized the importance of considering soil texture and climate conditions when choosing suitable agricultural practices (link).

In a separate case study, the effects of different fertilizers (compost, digestate, liquid pig slurry, and ammonium nitrate) and soil tillage practices (conventional and minimum tillage) on N2O emissions from the soil were investigated. Despite calculating fertilizer rates to meet crop nitrogen requirements, the results indicated that N2O emissions exceeded the standard EF value of 1% in the Po Valley climatic conditions, specifically in silt loam soil. However, reduced tillage and the use of

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digestate and compost under conventional tillage were shown to reduce emissions factors, suggesting potential mitigation strategies for nitrogen emissions (link).

To unlock the full potential of precision agriculture and advance sustainability and resilience in farming, the need for appropriate criteria in economic assessment is crucial. One of the studies introduces a web tool designed to evaluate the net economic benefits of integrating precision farming technologies in various contexts. Despite the importance of adopting new technologies for farmers' competitiveness, PA is a complex system demanding a shift from empirical to data-driven decision-making, with benefits challenging to quantify in advance. A notable knowledge gap between farmers and technology developers complicates the communication of PA's economic and environmental advantages. Successful adoption of PA technologies hinges on farmers' efforts and confidence, requiring continuous integration of new knowledge to address uncertainties about potential benefits (link).

It is noteworthy that, according to the information available, the combination of farm practices using digestate, precision agriculture, and no-tillage appeared less common, with digestate often being combined with conventional tillage practices or synthetic fertilizers. This observation underscores the need for further research and exploration of integrated approaches that incorporate these practices for sustainable and efficient farming systems.

5.1.6 Conclusions

Due to different production conditions, standard and innovative, variable costs also differ. Within the financial analysis of the innovative scenario, costs of digestate application and GPS locator are included. The cost of the GPS locator has been incorporated as a long-term asset (amortization rate applied in the calculation).

The application rate of digestate has been determined and harmonized according to the official fertilization management recommendations for the specific crop production and optimal N application.

The majority of prices used in the analysis refer to official market data from 2019. This year has been selected as a reference year due to numerous geopolitical conditions that made a significant market disturbance across the globe (pandemic, wartime in 2022).

For standard wheat production, variable costs are 601.92 €/ha in Croatia and 675.00 €/ha in Belgium. In contrast, employing innovative principles raises costs to 890.54 €/ha in Croatia and 971 €/ha in Belgium. The gross margin calculation (excluding machinery costs) in Croatia is 238.08 €/ha for the standard scenario and -50.54 €/ha for the innovative one due to higher production costs. In Belgium, the gross margin is 1,091.57 €/ha in the standard scenario and 795.57 €/ha in the innovative one.

Despite the higher costs, combining no-till practices and using digestate as the primary nitrogen source proves beneficial for soil organic matter, offering both short- and long-term sustainability for wheat production. This approach doesn't compromise yield quality or quantity, making it a viable and eco-friendly choice.

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Table 28. Overview of data used as reference to CBA study

Data	Reference CBA Study	Type of data	Source of data (Croatia)	Source of data (Flanders)
Reference scenario of wheat (yield, unit price)	Table 21	Sector publication	The data of the advisory service of the Ministry of Agriculture	Sector information (stakeholder interaction
Reference scenario of wheat – production cost (seed, mineral fertilizers, pesticides, energy, other costs)	Table 21	Sector publication	The data of the advisory service of the Ministry of Agriculture	Sector information (stakeholder interaction
Reference scenario of wheat - Total production costs	Table 21	Project produced data	D3.3	D3.3
Reference scenario of wheat – mechanization cost (rented mechanization, own mechanization, rent land, cost of contract work)	Table 21	Sector publication	The data of the advisory service of the Ministry of Agriculture	Sector information (stakeholder interaction
Total harvesting costs	Table 21	Project produced data	D3.3	D3.3
Total costs (production cost + harvesting cost)	Table 21	Project produced data	D3.3	D3.3
Reference scenario of wheat - Gross Margin Calculation (GMC)	Table 21	Project produced data	D3.3	D3.3
Reference scenario of wheat - Unit price (€/kg)	Table 22	Sector publication	TISUP	
Reference scenario of wheat - Gross margin calculation (€/ha) (no machinery costs)	Table 22	Project produced data	D3.3	D3.3
Reference scenario of wheat - Gross margin calculation (€/ha) (including machinery costs)	Table 22	Project produced data	D3.3	D3.3
Composition CAN	Table 23	Sector publication	The data of the advisory service of the Ministry of Agriculture	
Composition UREA	Table 23	Sector publication	The data of the advisory service of the Ministry of Agriculture	
Composition NPK	Table 23	Sector publication	The data of the advisory service of the Ministry of Agriculture	
Composition NPK	Table 23	Sector publication	The data of the advisory service of the Ministry of Agriculture	
Overview of N2C case scenario	Table 20	Project produced data	D2.3	D2.3
Innovative scenario – (yield, unit price)	Table 24	Sector publication	The data of the advisory service of the Ministry of Agriculture	
Innovative scenario – production cost (seed, pesticides, GPS geolocator, digestate, other costs)	Table 24	Sector publication	The data of the advisory service of the Ministry of Agriculture	
Innovative scenario – total production cost	Table 24	Project produced data	D3.3	D3.3
Innovative scenario – mechanization cost (no-tillage system, land rent)	Table 24	Sector publication	The data of the advisory service of the Ministry of Agriculture	
Innovative scenario – total harvesting cost	Table 24	Project produced data	D3.3	D3.3

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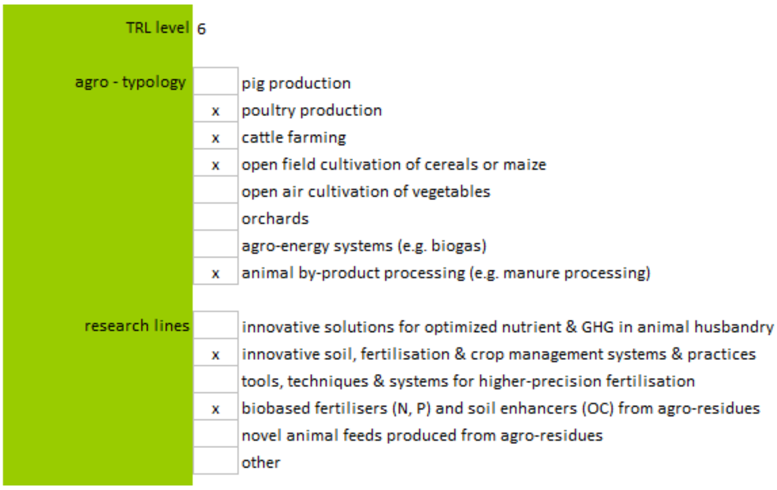
Innovative scenario - Gross margin calculation	Table 24	Project produced data	D3.3	D3.3
Innovative scenario – unit price (€/kg)	Table 25	Sector publication	TISUP	
Innovative scenario - Gross margin calculation (€/ha) (no machinery costs)	Table 25	Project produced data	D3.3	D3.3
Innovative scenario- Gross margin calculation (€/ha) (including machinery costs)	Table 25	Project produced data	D3.3	D3.3
Recommended fertilization plan if digestate from the innovative case is being used	Table 26	Sector publication	The data of the advisory service of the Ministry of Agriculture	
Fertilization cost of ammonium sulphate and digestate	Table 26	Sector publication	The data of the advisory service of the Ministry of Agriculture	
Amounts of total organic carbon added by recommended fertilization plan for digestate	Table 27	Sector publication	The data of the advisory service of the Ministry of Agriculture	

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

This study aimed to assess agronomic benefits (build soil C, N, P fertility) of different bio-based recycling derived fertilisers at field-scale trials for increasing nutrient recovery and recycling from different agri-food processing waste resources and thus facilitating farmers' understanding to use these options and to replace chemical fertilisers.

For the grassland trial, 7 bio-based products have been used - 2 products from the dairy food processing industry-based wastewater treated by-products – bio-chemically treated activated sludge and lime treated dissolved air flotation-based sludge; 2 types of struvite (recovered phosphate mineral) – processed from sewage and potato wastewater effluent; 2 types of P rich ash – processed from sewage sludge and poultry litter. Cattle slurry was included for the P-FRV and balanced fertiliser efficiency. A trial was set up using a randomised block layout for P FRV and balance fertiliser plots respectively, with 5 replications for each treatment. The individual plots measured 2 m wide by 6 m long placed alongside each other with the spray lines used as a buffer strip. For the arable land trial five bio-based products – 2 dairy food processing industry-based wastewater treated by-products, chicken litters (poultry and broiler manure) and cattle slurry were included. The arable land experimental plots (28 plots @ 10x3 m^2) were established in a crop farmer's farmland located at Arklow, Co. Wicklow.



TRL level	6	
agro - typology		pig production
	x	poultry production
	x	cattle farming
	x	open field cultivation of cereals or maize
		open air cultivation of vegetables
		orchards
		agro-energy systems (e.g. biogas)
	x	animal by-product processing (e.g. manure processing)
research lines		innovative solutions for optimized nutrient & GHG in animal husbandry
	x	innovative soil, fertilisation & crop management systems & practices
		tools, techniques & systems for higher-precision fertilisation
	x	biobased fertilisers (N, P) and soil enhancers (OC) from agro-residues
		novel animal feeds produced from agro-residues
		other

Figure 11. LL17 Technology TRL, agro-typology and research lines

5.2.1 Background information

Maize production

Maize is a cereal grain that is considered a commodity and a staple food in multiple parts of the world, including Europe (link). It is one of the most important cereal crops used in the human diet and it is an important feed component for livestock. Maize yields may be higher than 25 tonnes per hectare (link).

The leading maize-producing countries in Europe are Ukraine, France, Italy, and Romania. Even though the EU has the largest market share in the global maize export, it imports 13 % of the total maize produced globally (link).

It is estimated that the production of grain maize in Croatia increased by 9.8 % in 2020 as compared to the previous year. About 2.33 million tonnes of maize were produced in 2020, one per cent higher than in 2019, when 2.29 million tonnes were produced. Maize was sown at 258.000 ha and the achieved average production of maize per hectare was 9 tons, the same yield as in 2019, according to the Smarter analysis (link). In Croatia and Slovenia, maize is, according to harvested areas leading crop, with average yields above the world average (link).

Though Belgium's maize yield fluctuated substantially in recent years, it tended to decrease through the 2001 – 2020 period ending at 81.151 t/ha in 2020 (link).

Grassland production

In its narrow sense, 'grassland' may be defined as ground covered by vegetation dominated by grasses, with little or no tree cover. UNESCO defines grassland as "land covered with herbaceous plants with less than 10 % tree and shrub cover." Grasslands cover around 282.000 km^2, corresponding to 14.6 % of the total area in the countries of Eastern Europe, here defined as East Europe, Eastern Central Europe, and the non-Mediterranean part of the Balkan Peninsula (link).

Permanent grassland accounted for almost one third (31.2 %) of the utilised agricultural area and was mainly used to provide further fodder and forage for animals (link).

In Belgium total area of grassland in 2018 was 28.2 %, while in Croatia share of the total area of grassland was 17.4 % (link). Grassland management systems in Belgium are also quite diverse, although they are intensive almost everywhere. Given that Croatia is abundant in areas under grassland, grassland should be the main resource to produce fodder. Unfortunately, the main feature of most of the permanent grassland is a poor botanical composition and low yields of fodder, whereas high-quality fodder yields can be observed on saturated grassland.

5.2.2 N2C case scenario

The N2C scenario aimed to assess agronomic benefits of different biobased recycling derived fertilisers at field-scale trials for increasing nutrient recovery and recycling from different agri-food processing waste resources.

Tables 29 and 30 indicate the most important parameters of the case scenario, including information on crops rotated, fertilisation and chemical management as well as soil properties.

Arable farmland

Table 29. Overview of N2C case scenario

Waste input	-
Main product	-
By-products	-
Crop rotation	Arable farmland - rotational crops – Maize (2019), Wheat (2020), and 2021 (Oilseed rape – in progress)
Fertilisation management	Arable crop trial: N, P, K, S fertilisation using the balanced application of biobased and chemical fertilisers before sowing a new crop.
Application of products from innovative technology	Main product or by-products from innovative technologies to be applied on the field, i.e., digestate from biogas production. Physical, chemical properties (e.g., C, N, P content, DM(%),…)
Application rates	I/P
Nutrient concentrations in digestates, manure	Cattle Slurry DM: 9.0 OM: 70.6 N: 3.3 P: 0.6 K: 4.3 S: 0.4 Total C: 39.2

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	Diary sludge DM: 12.2
Soil properties	Arable trial site: Total C 1.8%, OM 4.5%, N 0.2%, Morgan's soil P 6.3 mg/L, pH 6.5, sandy loam soil.
Saving rates for fertilizers such as the substitution of min. fertilizer with manure	I/P

Grassland

Table 30. Overview of N2C case scenario

Waste input	-
Main product	-
By-products	-
Crop rotation	Grassland - silage production (2019 & 2020 completed, 2021- in progress)
Fertilisation management	Grassland trial: N, P, K, S fertilization 3 times per year using the balanced application of biobased and chemical fertilisers.
Application of products from innovative technology	Main product or by-products from innovative technologies to be applied on the field, i.e., digestate from biogas production. Physical, chemical properties (e.g., C, N, P content, DM (%),…)
Application rates	I/P
Nutrient concentrations in digestates, manure	Cattle Slurry DM: 9.0 OM: 70.6 N: 3.3 P: 0.6 K: 4.3 S: 0.4 Total C: 39.2 Diary sludge DM: 12.2
Soil properties	Grassland: Total C 2.5%, organic C 1.8%, N 0.3%, Morgan's soil P 2.86 mg/L, pH 5.6, sandy loam textured soil (sand 54.9%, silt 30.1% and clay 15%).
Saving rates for fertilizers such as the substitution of min. fertilizer with manure	I/P

Both grassland and arable land trials were conceptualised in 2019. According to the research plan, three seasonal harvests were completed for the grassland trial and one tillage crop (spring maise) harvesting was completed for the arable land site in 2019. Soil and crop samples from all harvests have been processed and prepared for the required analysis. The preliminary results from both grassland and arable land trials indicate that the fertiliser efficiency of several selected bio-based fertiliser products is statistically similar to chemical fertiliser in terms of achieving DM yield.

The balanced application of bio-based fertiliser products can achieve similar grass production which has great potential to reduce and replace the use of mineral fertilisers and ensure cost savings.

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Furthermore, results show that applied bio-based fertiliser products in this trial can achieve similar maise production to what mineral-based chemical fertilisers provide.
It is expected that farmers can save some costs by replacing chemical fertilisers with the integrated use of chemical and bio-based fertiliser options. This would enhance the increasing recycling of C, N and P for crop production and benefit soil health by increasing soil organic carbon and organic matter.

5.2.3 Financial/Economic analysis – Reference scenario

Reference scenario implies to:

- Soil tillage, particularly primary tillage, as a foundation of any crop production system and is the biggest cost factor in maize production;
- Use of mineral fertilizers and pesticides (preventive control, cultivation control, biological control, nematode control, etc,..).

Gross margin calculations of maize and grassland production in standard conditions, as well as the effect of price and GMC on variable cost calculations for Croatia and Belgium, and finally the recommended fertilization plan for Croatia in 2019. is indicated in the following tables.

Table 31. Balance calculations for maize production in Croatia and Belgium (2019)

Reference scenario (Maize)			Croatia (2019)	Flanders (2019)
Benefits	Yield	kg/ha	9000	11511
	Unit price	€/ton	115	147
	Total income	**€/ha**	**1035**	**1692,12**
Production costs	Seed	€/ha	121,11	180
	Mineral fertilizers	€/ha	327,08	70
	Pesticides	€/ha	97,49	105
	Other costs (insurance, redemption, …)	€/ha	232,26	93
	Total production costs	**€/ha**	**777,9**	**448**
Mechanization costs	Rented mechanization	€/ha	80,74	177
	Own mechanization	€/ha	139,35	84
	Total harvesting costs	**€/ha**	**220,1**	**261**
TOTAL COSTS		**€/ha**	**998,0**	**709**
Gross Margin Calculation (GMC)		€/ha	37,0	983,12

Table 32. Effect of maize price and gross margin calculation on variable cost calculations in Croatia and Belgium

MAIZE	**Unit price (€/kg)**		**Gross margin calculation (€/ha)** (no machinery costs)		**Gross margin calculation (€/ha)** (including machinery cost)	
	CROATIA	**FLANDERS**	**CROATIA**	**FLANDERS**	**CROATIA**	**FLANDERS**
Extreme - low	-	-	-	-	-	-
lower price	0,110	0,125	212,06	990,88	- 8,03	729,88
average price	0,115	0,147	257,06	1244,12	36,97	983,12
higher price	0,121	0,169	311,06	1497,36	90,97	1236,36
Extreme - high	-	--	-	-	-	-

Gross margin calculation (GMC) is based on the determination of income and variable costs of production in the production season and/or calendar year. The structure of income in the calculations includes all revenues generated from the sale of products and other revenues generated in a particular production, which can be directly linked to production resource unit (support per ha/LU). The amount of income depends on the quantity of the manufactured product as well as the number of pieces sold and their price. When all the cost of renting machinery and/or the cost of own machinery are included in the calculation of the GMC, gross margin calculation obtains all costs .

Maize prices varied in the 2019 year. The lowest price for Croatia was 0,11 €, while the highest price was 0,12 €/kg. Furthermore, the lowest price in the 2022 year is 0,21 €, while the highest is 0,29 €. The average price of maize in 2022 is 0,25 €/kg.

The lowest price of maize in Belgium for 2020 year was 0,13 €/kg, while the highest price was 0,20 €/kg. The average price for 2020. was 0,18 €/kg. On the other hand, prices in 2021. were significantly higher, and the average price of corn was 0,24 €/kg.

The data of the advisory service of the Ministry of Agriculture and the prices stated in the market information system (TISUP) were used as a source and reference of prices for the gross margin calculation for Croatia.

Table 33. Recommended fertilization plan for standard maize production in Croatia (2019) (link)

Recommended fertilization Maize (Croatia 2019)					Applied fertilizers / ha				**Fertilizer costs**
Type of fertilizer	Kg N / kg	kg P2O5 / kg	kg K2O / kg	€/kg	**Total kg fertilizers**	**N**	**P2O5**	**K2O**	**€/ha**
CAN	0.27			0.21	**180**	49			**37.8**
UREA	0.46			0.3	**100**	46			**30**
NPK	0.07	0.2	0.3	0.5	**450**	32	90	135	**225**
NPK	0.15	0.15	0.15	0.32	**150**	23	23	23	**48**
Total					**880**	**149**	**113**	**158**	**340.8**

Table 34. Balance calculations for grassland production in Croatia (2019)

Baseline info (Grassland) - Haylage			**Croatia (2019)**
Benefits	Number of outlets	-	3
	Dry matter	kg/ha	6000
	Yield	kg/ha	15000
	Unit price	€/ton	110
	Total income	**€/ha**	1.650
Production costs	Seed	€/ha	37,99
	Mineral fertilizers	€/ha	142,18
	Total production costs	**€/ha**	**180,09**
Harvesting costs	Rented mechanization	€/ha	311,54
	Own mechanization	€/ha	209,41
	Total harvesting costs	**€/ha**	**520,95**
TOTAL COSTS		**€/ha**	**701,04**
	Gross Margin Calculation (GMC)	€/ha	948,96

Table 35. Effect of grassland price and gross margin calculation on variable cost calculations in Croatia (2019)

GRASSLAND	**Unit price (€/kg)**	**Gross margin calculation (€/ha)** (no machinery costs)	**Gross margin calculation (€/ha)** (including machinery cost)
Extreme - low	-	-	-
lower price	0,07	869,91	348,96
average price	0,11	1.469,82	948,96
higher price	0,21	2.969,82	2.448,96
Extreme - high	-	-	-

The lowest price of grassland in Croatia for 2019 was 0,07 €/kg, while the highest price was 0,21 €/kg. The average price for 2019 was 0,11 €/kg.

Table 36. Recommended fertilization plan for standard grassland production in Croatia (2019)

Recommended fertilization Grassland (Croatia 2019)					Applied fertilizers / ha				**Fertilizer costs**
Type of fertilizer	Kg N / kg	kg P_2O_5 / kg	kg K_2O / kg	€/kg	**Total kg fertilizers**	**N**	**P_2O_5**	**K_2O**	**€/ha**
CAN	0.27			0,21	**600**	162			**126**
NPK	0.07	0.2	0.3	0,47	**400**	28	80	120	**188**
Total					**1000**	**190**	**80**	**120**	**314**

5.2.4 Cost-benefit analysis – Innovative scenario

The innovative scenario refers to:

- Agronomic benefits (build soil C, N, P fertility) of different biobased recycling derived fertilisers for increasing nutrient recovery and recycling from different processing waste resources.

By applying bio-based fertilizers such as products from the dairy food processing industry, struvite, processed sewage and potato wastewater effluent, ash, processed sewage sludge and poultry litter, most nutrients will be used and the need for mineral fertilizers will be reduced.

Gross margin calculations of maize and grassland production in innovative conditions, as well as the effect of price and GMC on variable cost calculations for Croatia and Belgium, and finally the recommended fertilization plan is indicated in the following tables. The established price of bio-based fertilizers, which is used for calculations in the innovative scenarios, refers to the average price of organic fertilizers obtained through table 41. Average price of bio-based fertilizers is 323.2 €/ha.

Table 37. Balance calculations for grassland production in innovative scenario

Innovative scenario (Grassland)			Haylage
Benefits	Number of outlets	-	3
	Dry matter	kg/ha	6000
	Yield	kg/ha	15000
	Unit price	€/ton	110
	Total income	**€/ha**	1650
Production costs	Seed	€/ha	37,99
	Bio-based fertilizers	€/ha	323,2

	Total production costs	**€/ha**	**361,19**
Machinery costs	Rented mechanization	€/ha	311,54
	Own mechanization	€/ha	209,41
	Total harvesting costs	**€/ha**	**520,95**
TOTAL COSTS		**€/ha**	**882,14**
	Gross Margin Calculation (GMC)	€/ha	767,86

Table 38. Effect of grassland price and gross margin calculation on variable cost calculations in innovative cases, if applied in Croatia (2019)

GRASSLAND	**Unit price (€/kg)**	**Gross margin calculation (€/ha)** (no machinery costs)	**Gross margin calculation (€/ha)** (including machinery cost)
Extreme - low	-	-	-
lower price	0,07	688,81	167,86
average price	0,11	1.288,81	767,86
higher price	0,21	2.788,81	2.267,86
Extreme - high	-	-	-

For the effect of grassland price and gross margin calculation on variable cost calculations in innovative cases, it is considered to be the same for Belgium.

Table 39. Gross margin calculations for maize production in innovative scenario

Innovative scenario (Maize)			**Croatia (2019)**	**Belgium (2019)**
Benefits	Yield	kg/ha	9000	11511
	Unit price	€/ton	115	147
	Total income	**€/ha**	**1035**	**1692,12**
Production costs	Seed	€/ha	121,11	180
	Bio-based fertilizers	€/ha	323,2	323,2
	Pesticides	€/ha	97,49	105
	Other costs (insurance, redemption, …)	€/ha	232,26	93
	Total production costs	**€/ha**	**774,06**	**701,2**
Machinery costs	Rented mechanization	€/ha	260,94	177
	Own mechanization	€/ha	139,35	84
	Total harvesting costs	**€/ha**	**400,29**	**261**
TOTAL COSTS		**€/ha**	**1.174,35**	**962,2**
	Gross Margin Calculation (GMC)	€/ha	-139,35	729,92

Table 40. Effect of grassland price and gross margin calculation on variable cost calculations in innovative cases, if applied in Croatia and Belgium (2019)

MAIZE	**Unit price (€/kg)**		**Gross margin calculation (€/ha)** (no machinery costs)		**Gross margin calculation (€/ha)** (including machinery cost)	
	CROATIA	**BELGIUM**	**CROATIA**	**BELGIUM**	**CROATIA**	**BELGIUM**
Extreme - low	-	-	-	-	-	-
lower price	0,110	0,125	215,94	737,68	-184,35	476,68
average price	0,115	0,147	260,94	990,92	-139,35	729,92

higher price	0,121	0,169	314,94	1.244,16	-85,35	983,16
Extreme - high	-	-	-	-	-	-

Table 41. Applied treatments and cost

Treatments	Fertiliser Programme (kg/ha)	N availability (%)	Cost (€/ha)
Chemical fertiliser (CF)	180N, 40P, 190K, the 20S from CF	100	453
Poultry manure (PM)	4020 PM + CF (95N, 0P, 109K, 4S)	63	285
Broiler manure (BM)	8329 BM + CF (97N, 0P, 41K, 0S)	50	336
Cattle slurry (CS)	33052 CS + CF (146N, 16.5P, 25K, 6S)	30	312
DAF sludge (DS)	1335 DS + CF (178N, 0P, 189K, 19S)	31	349
Activated sludge (AS)	10653 AS + CF (174N, 0P, 184K, 13S)	11	334

5.2.5 Comparative analysis of innovative scenario and published research

This technology aims to evaluate the agronomic benefits of different bio-based recycling-derived fertilizers in field-scale trials, focusing on nutrient recovery and recycling from agri-food processing waste. The bio-based fertilizers, derived from dairy food processing, struvite, processed sewage, potato wastewater, ash, sewage sludge, and poultry litter, were assessed for their effectiveness in enhancing soil carbon, nitrogen, and phosphorus fertility. The goal was to reduce the dependence on mineral fertilizers and promote sustainable farming practices, particularly in maize and grassland cultivation.

In standard maize production, the variable costs were 777.90 €/ha in Croatia and 448 €/ha in Flanders. However, the adoption of innovative principles increased costs to 701.20 €/ha in Flanders, while in Croatia, innovative practices resulted in costs similar to standard production at 774.06 €/ha. The gross margin calculation (excluding machinery costs) indicated a margin of 37.00 €/ha for standard production and -139.35 €/ha for innovative practices in Croatia. In Flanders, the gross margin was 983.12 €/ha for standard production and 729.92 €/ha for innovative practices. For grassland, the total production cost for the reference scenario was 180.09 €/ha, increasing to 361.19 €/ha with innovative practices. The gross margin calculations showed a margin of 948.96 €/ha for the reference scenario and 767.86 €/ha for the innovative one.

Cost variations were influenced by the treatment and fertilization program. Chemical fertilizers incurred the highest cost at 453 €/ha, while the lowest cost was associated with poultry manure at 285 €/ha. There were generally no significant differences in the implementation costs of broiler manure, cattle slurry, DAF sludge, and activated sludge. The findings highlight the economic implications of adopting innovative practices, emphasizing the potential trade-offs between increased costs and improved sustainability in nutrient management for maize and grassland cultivation.

One of the examples of the benefits of organic fertilizers is foreseen within the research. Organic fertilizers were derived from expired dairy waste for fertilizing wheat crops, during 2-year field trials. The soil quality (sandy soils with low fertility) was improved and wheat growth was enhanced. Organic

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fertilizer outperformed mineral fertilizers, it increased the grain yield by 22–35 % and the straw yield by 15–17 %, increased chlorophyll by 11 % and 16 % in the first and second seasons, also increased the uptake of N, P, and K by 55 %, 49 %, and 51 % above the inorganic nutrition (link).

Agriculture significantly contributes to global greenhouse gas emissions. Circular economy practices, particularly in bioenergy utilization, offer environmental benefits in the agro-industrial sector. Despite only 9 % of the global economy being circular, initiatives are working to shift from the linear model to a circular one, focusing on sustainable material and energy flows. Regarding to that, one of the study aims to map bioenergy boosters through circular economy practices in agriculture, conducting a systematic literature review to identify key research themes, applications, and trends. Results show a recent surge in interest, with European countries leading in publications. Notably, electricity generation and biofuel from biogas emerge as sustainable opportunities (link).

5.2.6 Conclusions

Although the use of mineral fertilizers significantly improves the quality and quantity of food, their long-term and uncontrolled use often causes environmental problems (soil, water and air pollution) and is associated with deteriorating soil structure, reducing microflora, water pollution, human and animal food (link). Replacing mineral fertilisers with organic fertilisers reduces the incidental harmful effects of mineral fertilizers, in addition it improves the intake of nutrients, helps to improve soil structure, better water retention and nutrients in the soil.

Large quantities of by-products produced on farms need to be disposed of somewhere, and transport is quite expensive. Utilizing OM would greatly reduce the costs of disposal and cost of purchasing mineral fertilizers.

In standard maize production, variable costs are 777.90 €/ha in Croatia and 448 €/ha in Flanders. However, employing innovative principles increases costs in Flanders to 701.20 €/ha, while in Croatia, innovative practices result in costs similar to standard production at 774.06 €/ha. The gross margin calculation (excluding machinery costs) in Croatia is 37.00 €/ha for standard production and -139.35 €/ha for innovative, while in Flanders, it's 983.12 €/ha for standard and 729.92 €/ha for innovative.

For grassland, the total production cost for the reference scenario is 180.09 €/ha, increasing to 361.19 €/ha with innovative practices. The gross margin calculations are 948.96 €/ha for the reference scenario and 767.86 €/ha for the innovative one.

Cost variations depend on the treatment and fertilization program. Chemical fertilizers incur the highest cost at 453 €/ha, while the lowest is with poultry manure at 285 €/ha. There are generally no significant differences in the implementation costs of broiler manure, cattle slurry, DAF sludge, and activated sludge (Table 41). The average price of bio-based fertilizers, derived from the input in table 41, is 323.2 €/ha.

Table 42. Overview of data used as reference to CBA study

Data	Reference CBA Study	Type of data	Source of data (Croatia)	Source of data (Flanders)
Reference scenario of maize (yield, unit price)	Table 31	Sector publication	The data of the advisory service of the Ministry of Agriculture	Sector information (stakeholder interaction)
Reference scenario of maize – production cost (seed, mineral fertilizers, pesticides, energy, other costs)	Table 31	Sector publication	The data of the advisory service of the Ministry of Agriculture	Sector information (stakeholder interaction)

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Reference scenario of maize - Total production costs	Table 31	Project produced data	D3.3	D3.3
Reference scenario – mechanization cost (rented mechanization, own mechanization)	Table 31	Sector publication	The data of the advisory service of the Ministry of Agriculture	Sector information (stakeholder interaction)
Total harvesting costs	Table 31	Project produced data	D3.3	D3.3
Total costs (production cost + harvesting cost)	Table 31	Project produced data	D3.3	D3.3
Reference scenario of wheat - Gross Margin Calculation (GMC)	Table 31	Project produced data	D3.3	D3.3
Reference scenario - Unit price (€/kg)	Table 32	Sector publication	TISUP	
Reference scenario - Gross margin calculation (€/ha) (no machinery costs)	Table 32	Project produced data	D3.3	D3.3
Reference scenario - Gross margin calculation (€/ha) (including machinery costs)	Table 32	Project produced data	D3.3	D3.3
Composition CAN	Table 33	Sector publication	The data of the advisory service of the Ministry of Agriculture	
Composition UREA	Table 33	Sector publication	The data of the advisory service of the Ministry of Agriculture	
Composition NPK	Table 33	Sector publication	The data of the advisory service of the Ministry of Agriculture	
Composition NPK	Table 33	Sector publication	The data of the advisory service of the Ministry of Agriculture	
Fertilizer costs (CAN, UREA, NPK, NPK)	Table 33	Sector publication	TISUP	
Baseline info (grassland) – benefits (number of outlets, dry matter, yield, unit price)	Table 34	Sector publication	The data of the advisory service of the Ministry of Agriculture	
Baseline info (grassland) – production cost (seed, mineral fertilizer)	Table 34	Sector publication	The data of the advisory service of the Ministry of Agriculture	
Baseline info – total production cost	Table 34	Project produced data	D3.3	D3.3
Baseline info (grassland) – harvesting cost (rented mechanization, own mechanization)	Table 34	Sector publication	The data of the advisory service of the Ministry of Agriculture	
Baseline info (grassland) – total harvesting cost	Table 34	Project produced data	D3.3	D3.3
Baseline info (grassland) – total cost	Table 34	Project produced data	D3.3	D3.3
Baseline info (grassland) – Gross margin calculation	Table 34	Project produced data	D3.3	D3.3
Reference scenario - Unit price (€/kg)	Table 35	Sector publication	TISUP	
Baseline info - Gross margin calculation (€/ha) (no machinery costs)	Table 35	Project produced data	D3.3	D3.3
Baseline info - Gross margin calculation (€/ha)	Table 35	Project produced data	D3.3	D3.3

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(including machinery costs)				
Recommended fertilization plan for standard grassland production in Croatia	Table 36	Sector publication	The data of the advisory service of the Ministry of Agriculture	
Fertilizer cost (CAN, NPK)	Table 36	Sector publication	TISUP	
Overview of N2C case scenario – arable farmland	Table 29	Project produced data	D2.6	D2.6
Overview of N2C case scenario – grassland	Table 30	Project produced data	D2.6	D2.6
Innovative scenario (grassland) – benefits (number of outlets, dry matter, yield, unit price)	Table 37	Sector publication	The data of the advisory service of the Ministry of Agriculture	
Innovative scenario (grassland) – production cost (seed, bio-based fertilizer)	Table 37	Sector publication	The data of the advisory service of the Ministry of Agriculture	
Innovative scenario – total production cost	Table 37	Project produced data	D3.3	D3.3
Innovative scenario (grassland) – machinery cost (rented mechanization, own mechanization)	Table 37	Sector publication	The data of the advisory service of the Ministry of Agriculture	
Innovative scenario (grassland) – total harvesting cost	Table 37	Project produced data	D3.3	D3.3
Innovative scenario (grassland) – total cost	Table 37	Project produced data	D3.3	D3.3
Innovative scenario (grassland) – Gross margin calculation	Table 37	Project produced data	D3.3	D3.3
Innovative scenario - Unit price (€/kg)	Table 38	Sector publication	TISUP	
Innovative scenario - Gross margin calculation (€/ha) (no machinery costs)	Table 38	Project produced data	D3.3	D3.3
Innovative scenario - Gross margin calculation (€/ha) (including machinery costs)	Table 38	Project produced data	D3.3	D3.3
Innovative scenario (maize) – benefits (yield, unit price)	Table 39	Sector publication	The data of the advisory service of the Ministry of Agriculture	
Innovative scenario (maize) – production cost (seed, bio-based fertilizers, pesticides, other cost)	Table 39	Sector publication	The data of the advisory service of the Ministry of Agriculture	
Innovative scenario – total production cost	Table 39	Project produced data	D3.3	D3.3
Innovative scenario (maize) – machinery cost (rented mechanization, own mechanization)	Table 39	Sector publication	The data of the advisory service of the Ministry of Agriculture	
Innovative scenario (maize) – total harvesting cost	Table 39	Project produced data	D3.3	D3.3
Innovative scenario (maize) – total cost	Table 39	Project produced data	D3.3	D3.3
Innovative scenario (maize) – Gross margin calculation	Table 39	Project produced data	D3.3	D3.3
Innovative scenario - Unit price (€/kg)	Table 40	Sector publication	TISUP	
Innovative scenario - Gross margin calculation (€/ha) (no machinery costs)	Table 40	Project produced data	D3.3	D3.3

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Innovative scenario - Gross margin calculation (€/ha) (including machinery costs)	Table 40	Project produced data	D3.3	D3.3
Fertiliser Programme (kg/ha) - Chemical fertiliser (CF)	Table 41	Sector publication	The data of the advisory service of the Ministry of Agriculture	Sector information (stakeholder interaction)
Fertiliser Programme (kg/ha) - Poultry manure (PM)	Table 41	Sector publication	The data of the advisory service of the Ministry of Agriculture	Sector information (stakeholder interaction)
Fertiliser Programme (kg/ha) - Broiler manure (BM)	Table 41	Sector publication	The data of the advisory service of the Ministry of Agriculture	Sector information (stakeholder interaction)
Fertiliser Programme (kg/ha) - Cattle slurry (CS)	Table 41	Sector publication	The data of the advisory service of the Ministry of Agriculture	Sector information (stakeholder interaction)
Fertiliser Programme (kg/ha) - DAF sludge (DS)	Table 41	Sector publication	The data of the advisory service of the Ministry of Agriculture	Sector information (stakeholder interaction)
Fertiliser Programme (kg/ha) - Activated sludge (AS)	Table 41	Sector publication	The data of the advisory service of the Ministry of Agriculture	Sector information (stakeholder interaction)

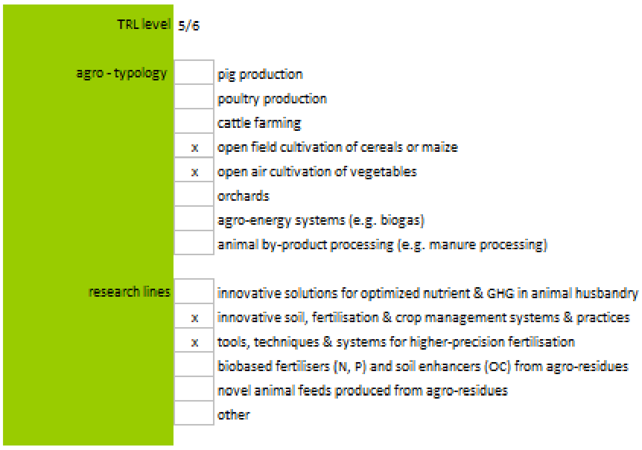
6. Research Line 3: Tools, techniques & systems for higher-precision fertilization

6.1 LL30 & LL73 Precision arable farming using bio-based fertilizers in potato growing

This solution aims to compare the effect of using different types of bio-based fertilisers instead of chemical fertilisers in a one-year experiment on a potato farm. The study is carried out at Van den Borne Potato Farm in Reusel (The Netherlands). The strategy is to reach 100 % chemical fertilizer free while maintaining optimal yield in potatoes by phasing out chemical N in 4 years to 70 %, 50 %, 25 % and fourth year 0 %.

The trial field (5 ha) was subdivided into eight equal blocks, and a site-specific management plan is randomly allocated to one of the blocks. Four of these blocks received different amounts of chemical N fertiliser to be able to draw a yield curve.

One of these plots received 0 % N fertiliser, and one of these blocks receive 50 % of the recommended amount of N fertiliser. Two of the blocks received each type of bio-based fertiliser to analyse the effect of replacing chemical N fertiliser for a bio-based fertiliser. One plot receives scrubbing salt ($(NH_4)_2SO_4$), and the other plot receives a liquid fraction of anaerobic digestion after enhanced removal of solids (a product where P is removed).



TRL level	5/6	
agro - typology		pig production
		poultry production
		cattle farming
	x	open field cultivation of cereals or maize
	x	open air cultivation of vegetables
		orchards
		agro-energy systems (e.g. biogas)
		animal by-product processing (e.g. manure processing)
research lines		innovative solutions for optimized nutrient & GHG in animal husbandry
	x	innovative soil, fertilisation & crop management systems & practices
	x	tools, techniques & systems for higher-precision fertilisation
		biobased fertilisers (N, P) and soil enhancers (OC) from agro-residues
		novel animal feeds produced from agro-residues
		other

Figure 12. LL73 Technology TRL, agro-typology and research lines

6.1.1 Background information

Precision arable farming

Precision farming or precision agriculture is generally defined as an information and technology-based farm management system to identify, analyse and manage spatial and temporal variability within fields for optimum productivity and profitability, sustainability and protection of the land resources by minimizing the production costs (link). Three major components of precision agriculture are information, technology, and management.

Precision farming is based on the optimised management of inputs in a field according to actual crop needs. It involves data-based technologies, including satellite positioning systems like GPS, remote sensing and the Internet, to manage crops and reduce the use of fertilisers, pesticides and water (link).

Precision agriculture gives farmers the ability to use crop inputs including fertilizers, pesticides, tillage and irrigation water more effectively. More effective use of inputs results in greater crop yield and quality, without polluting the environment (link).

Variable-rate fertiliser application is a commonly used technique in precision agriculture that increases the nutrient use efficiency and reduces environmental nutrient loss (Baeckström et al., 2006; Batte and Ehsani, 2006; Karkee et al., 2013; Lu et al., 2019; Obreza and Sartain, 2010).

Bio-based fertilisers

A transition towards sustainable agriculture is needed, not only to reduce the environmental impact of agricultural systems, but also to become more resilient to economic and societal challenges such as fluctuating production prices, changing consumer behaviour, and extreme weather events. One way to stimulate the transition towards sustainable and resilient farming systems is circular agriculture because it aims to minimise external inputs and negative discharges to the environment and to close nutrient cycles. Reducing the use of mineral fertilisers by using technologies that valorise biowaste into bio-based fertiliser (BBF) products can stimulate circularity (link). The use of biological waste is a practical solution to recover valuable fertilizer components (link).

Potato production

Potato (*Solanum tuberosum*) is grown in a 3 or more-year rotation with other crops such as maize, beans and alfalfa, to maintain soil productivity, to check weeds and to reduce crop loss from insect damage and diseases, particularly soil-borne disease. Fertilizer requirements of potato are relatively high, and it is best to apply organic fertilisers in basic fertilisation during autumn. Manure is the most often used organic fertiliser, and it is ploughed in autumn-winter fertilisation in the amount of 20-30 t/ha. To ensure optimal yields, the application of mineral fertilisers should provide: 100-140 kg N/ha, 100-120 kg P_2O_5/ha, 160-200 kg K_2O/ha.

In addition to manure, it is necessary to apply mineral NPK fertilisers with a pronounced content of phosphorus and potassium in the basic fertilisation. The largest share of mineral fertilisers, such as formulations NPK 5-15-30, NPK 7-20-30 and NPK (SO_3) 7-14-21, are applied in basic, deep soil tillage. The rest of the mineral fertilisers are applied in shallow tillage in preparation of the soil for planting, when NPK 15-15-15 or nitrogen fertilisers UREA or CAN are being used (link).

Potatoes were cultivated on 1.7 million hectares (ha) in the EU in 2020, and about 76,8 % of the EU's cultivated area of potatoes was concentrated in just 6 EU Member States: Poland (a provisional 21.6 %), Germany (16.5 %), France (12.9 %), Romania (10.0 %), the Netherlands (9.9 %) and Belgium (a provisional 5.9 %). The area of potatoes in the EU has been in long-term decline. The cultivated area almost halved between 2000 and 2020 (link).

Belgium's share in total EU's harvested production of potatoes in 2020 amounted to 7,2 %, and the share of Croatia was only 0,4 % (link). The average yield of potatoes in Croatia is 15.9 t/ha, and areas under potato production have been continuously reduced over the past four years. The production of potatoes in Croatia takes place each year at around 7.000 ha of agricultural areas (link).

The average price of potatoes in Croatia in 2022 is 0,49 €/kg. In Belgium, price for 1 kg of potatoes amounts to 1,36 € (range from 0,80 to 2,99 €) (link).

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

6.1.2 N2C case scenario

The N2C case scenario aims to compare the effect of using different types of bio-based fertilisers instead of chemical fertilisers in a one-year experiment on a potato farm. The strategy is to reach 100 % chemical fertilizer free while maintaining optimal yield in potatoes by phasing out chemical N in 4 years to 70 %, 50 %, 25 % and fourth year 0 %.

Table 43. indicates the most important parameters of the case scenario, including information on waste streams used and products obtained as well as digestate application rates used and soil characteristics on the site.

Table 43. Overview of N2C case scenario

Waste input	Pig manure (60 %) and digestate (40 %) in t/yr. Value: between -16 and -21 €/ton (PigBusiness,2021) Characteristics: 107 kg DM/t, 79 kg OM/t, 7 kg N-tot/t, 3.9 kg P_2O_5/t, 4.7 kg K_2O/ton, 1005 kg/m^3 (CBAV,2020)
Main product	Value: 50,000 t digestate results in 35,000 t liquid fraction (5.32 €/ton input), or 2037 (4,1 %) ammonium sulphate (7.36 €/ton input) Characteristics: Ammonium sulphate: 77 g N/kg, 67.1 g NH_3-N/kg, 9.9 g N-org/kg, 0.03 g P/kg, 0.07 g P_2O_5/kg, < 0.1 g K/kg
By-products	Value: clean water (0,40 €/t product to produce). 29713 l clean water/yr is produced Characteristics: thick fraction (high C-content, not measured). 15,000 t solid fraction out of 50,000 t digestate is produced. Costs are also 3,02 €/ton.
Crop rotation	Maize-potato crop rotation (the field was leased) 29th April: planting of potato (variety Fontane, size 40-50 mm) at 30 cm distance in the row.
Fertilisation management	80 t/ha pig manure 2 t/ha ammonium sulphate 31 t/ha liquid fraction ploughing 43 kg/ha magnesium sulphate 10.9 t/ha liquid fraction 40 t/ha liquid fraction 200 kg/ha KAS + S first probing 117 kg /ha Kali 60 second probing third probing harvest
Application of products from innovative technology	The products were applied in two stages - April and June. In total, the fields received ± 310 kg N/ha
Application rates	Replacing 100 % mineral fertiliser
Nutrient concentrations in digestates, manure	Scrubbing salt: higher N-concentration compared to liquid fraction and slurry. Scrubbing salt: the high concentration of SO3, liquid fraction higher concentrations of other nutrients compared to scrubbing salt.
Soil properties	N-tot = 3640 kg N/ha, C/N ratio 16, N-plant available - 45 kg N/ha, S-tot = 610 kg S/ha, C/S ratio: 98, S-plant available = 6 kg S/ha, P-tot=1470 kg P/ha, P plant available = 28,6

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	K-tot = 295, K plant available = 235 kg K/ha, Mg-plant available = 345 kg Mg/ha, pH = 5.7
Emission savings, including losses during application	Measured in the laboratory (in progress)
Saving rates for fertilizers such as the substitution of min. fertilizer with manure	Mineral N can be replaced by bio-based fertilisers. It will not replace slurry (as this brings in money for the arable farmer). The cost-efficiency of applying liquid fraction or scrubbing salt (in combination with the use of precision agricultural techniques will be tested in 2022).

6.1.3 Financial/Economic analysis – Reference scenario

The reference scenario of potato production implies:

- The use of mineral fertilizers, pesticides and mechanization for soil tillage.

Gross margin calculations of potato production in standard conditions, as well as the effect of price and GMC on variable cost calculations for Croatia and Belgium in 2019, and finally the recommended fertilization plan for Croatia in 2019, is indicated in the following tables.

Table 44. Balance calculation for potato production in Croatia and Belgium (2019)

Baseline info (Potato)			**Croatia (2019)**	**Belgium (2019)**
Benefits	Yield	kg/ha	30000	46231
	Early var.	€/ha	1.614,79	-
	Late var.	€/ha	2.422,19	-
	Unit price	€/ton	190	250
	Total income	**€/ha**	**5700**	**11.557,75**
Production costs	Seed	€/ha	2.447,75	902
	Mineral fertilizers	€/ha	447,43	250
	Pesticides	€/ha	605,69	685
	Energy	€/ha	150	150
	Other costs (insurance, redemption, …)	€/ha	-	125
	Total production costs	**€/ha**	**3.500,87**	**2112**
Harvesting costs	Rented mechanization	€/ha	672,83	354
	Own mechanization	€/ha	227,08	125
	Rent land	€/ha	-	750
	Cost of contract work	€/ha	-	600
	Total harvesting costs	**€/ha**	**899,91**	**1825**
TOTAL COSTS		**€/ha**	**4.400,78**	**3937**
Gross Margin Calculation (GMC)		€/ha	1.299,22	7.620,75

Table 45. Effect of potato price and gross margin calculation on variable cost calculations in Croatia and Belgium

POTATO	**Unit price (€/kg)**		**Gross margin calculation (€/ha)** (no machinery costs)		**Gross margin calculation (€/ha)** (including machinery cost)	
	CROATIA	**BELGIUM**	**CROATIA**	**BELGIUM**	**CROATIA**	**BELGIUM**
Extreme - low	-	-	-	-	-	-
lower price	0,15	0,16	999,12	5.284,96	99,22	3.459,96

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average price	0,19	0,25	2.199,12	9.445,75	1.299,22	7.620,75
higher price	0,27	0,34	4.599,12	13.606,54	3.699,22	11.781,54
Extreme - high	-	--	-	-	-	-

In 2019, the highest price of 1 kg of potatoes in Croatia was 0,27 €, the lowest 0,15 €, and the average price was 0,19 €. On the other hand, the highest price of 1 kg of potatoes in the 9th week of 2022 was significantly higher and amounted to 1,1 €, and the lowest price amounted to 0,27 €. The average price of 1 kg of potatoes in the 9th week of 2022 was 0,50 €.

The data of the advisory service of the Ministry of Agriculture and the prices stated in the market information system (TISUP) were used as a source of prices for the gross margin calculation for Croatia.

The lowest price of potatoes in Belgium in 2019 was 0,16 €/kg, the highest price was 0,34 €/kg, while the average price was 0,25 €/kg. In 2021, the average price of potatoes was higher than in 2019, and it amounted to 0,22 €/kg.

The majority of prices used in the analysis refer to official market data from 2019.

Table 46. Recommended fertilization plan for standard potato production in Croatia (2019) (link)

Recommended fertilization Potato (Croatia 2019)					Applied fertilizers / ha				**Fertilizer costs**
Type of fertilizer	Kg N / kg	kg P2O5 / kg	kg K2O / kg	€/kg	**Total kg fertilizers**	**N**	**P2O5**	**K2O**	**€/ha**
CAN	0.27			0,21	**200**	54			**42**
UREA	0.46			0,29	**100**	46			**29**
NPK	0.07	0.2	0.3	0,47	**800**	56	160	240	**376**
Total					**1100**	**156**	**160**	**240**	**447**

6.1.4 Cost-benefit analysis – Innovative scenario

The innovative scenario of potato production refers to:

- Precision arable farming with the use of bio-based fertilizers;
- Confirmation that chemical fertilisers can be replaced by biobased fertilisers on dry, sandy soils where potatoes are grown;
- The strategy focused no chemical fertilizer while maintaining optimal yield in potatoes by phasing out chemical N in 4 years to 70 %, 50 %, 25 % and in the fourth year to 0 %.

Gross margin calculations of potato production in innovative conditions, as well as the effect of price and GMC on variable cost calculations for Croatia and Belgium in 2019, and finally the recommended fertilization plan is indicated in the following tables.

Table 47. Balance calculation for innovative scenario in Croatia and Belgium

Innovative scenario (Potato)			**Croatia (2019)**	**Belgium (2019)**
Benefits	Yield	kg/ha	30000	46231
	Early	€/ha	1.614,79	-
	Late	€/ha	2.422,19	-
	Unit price	€/ton	190	250
	Total income	**€/ha**	**5700**	**11.557,75**
Production costs	Seed	€/ha	2.447,75	902

	Drone	€/ha	1300	1300
	Digestate	€/ha	56	56
	Pesticides	€/ha	605,69	685
	Total production costs	**€/ha**	**4.409,44**	**2943**
Harvesting costs	Rented mechanization	€/ha	672,83	354
	Own mechanization	€/ha	227,08	125
	Rent land	€/ha	-	750
	Cost of contract work	€/ha	-	600
	Total harvesting costs	**€/ha**	**899,91**	**1829**
TOTAL COSTS		**€/ha**	**5.309,35**	**4772**
Gross Margin Calculation (GMC)		€/ha	390,65	6.785,75

Table 48. Effect of potato price and gross margin calculation on variable cost calculations in innovative cases, if applied in Croatia and Belgium (2019)

POTATO	**Unit price (€/kg)**		**Gross margin calculation (€/ha)** (no machinery costs)		**Gross margin calculation (€/ha)** (including machinery cost)	
	CROATIA	**BELGIUM**	**CROATIA**	**BELGIUM**	**CROATIA**	**BELGIUM**
Extreme - low	-	-	-	-	-	-
lower price	0,15	0,16	90,56	4.453,96	-809,35	2.624,96
average price	0,19	0,25	1.290,56	8.614,75	390,65	6.785,75
higher price	0,27	0,34	3.690,56	12.775,54	2.790,65	10.946,54
Extreme - high	-	--	-	-	-	-

Table 49. Recommended fertilization plan if digestate from the innovative case is being used (2019) (link)

Recommended fertilization plan	kg	N	**P_2O_5**	**K_2O**	**Fertilizer costs (€/t)**
Digestate (77 g/kg TN, 0,03 g/kg P)	2.026	156	60,78	-	56
Ammonium sulphate (77 g/kg N)	2.026	156	-	-	36
Liquid fraction (4,55 g/kg N)	34.286	156	-	-	960,4

Ammonium sulphate characteristics:

77 g N/kg, 67.1 g NH3 - N/kg, 9.9 g N - org/kg, 0.03 g P/kg, 0.07 g P2O5/kg, < 0.1 g K/kg, < 0.2 g K2O/kg, < 0.4 g Na/kg, < 0.6 g Na2O/kg

Liquid fraction characteristics:

4.55 g N/kg, 3.5 g NH3 - N/kg, 1.1 g N - org/kg, 0.29 g P/kg, 0.66 g P2O5/kg, 5.7 g K/kg, 6.9 g K2O/kg, 3 g Na/kg, 4 g Na2O/kg, 0.01 SO3

6.1.5 Comparative analysis of innovative scenario and published research

The innovative scenario in potato production outlines a multifaceted approach that includes precision arable farming coupled with the utilization of bio-based fertilizers. The core elements of this strategy encompass confirming the viability of replacing chemical fertilizers with bio-based alternatives specifically tailored for dry, sandy soils where potatoes are cultivated. A significant aspect of this innovative strategy is the deliberate reduction of chemical nitrogen (N) over four years, progressively reaching a phased-out level of 70 %, 50 %, 25 %, and ultimately 0 % in the fourth year, while ensuring that optimal potato yields are maintained throughout this transition.

This innovative framework addresses both environmental and agronomic concerns, aiming to establish a sustainable and resource-efficient potato production system. The intentional reduction of chemical inputs, particularly nitrogen, is designed to minimize environmental impact and promote the use of bio-based fertilizers, fostering a more circular and environmentally friendly agricultural practice.

The benefits of BBF were tested within different publications. One of them investigated three Bio-Based Fertilizers (BBFs), namely the liquid fraction of digestate (LFD), potassium concentrate (KC), and ammonium sulfate solution (AS), in comparison with mineral fertilizer (link). BBFs were sourced from a mesophilic anaerobic co-digestion (AD) plant situated on a pig farm in Oirschot, the Netherlands. The study evaluated the agronomic and environmental performance of these BBFs in a precision agriculture-focused potato field experiment conducted in Eersel, 34 km away from the BBF production site. The crop rotation in this experiment involved one year of potatoes followed by three years of maize. Results indicated that all three BBFs can be considered safe alternatives to mineral fertilizer or slurry manure for potato cultivation on sandy soil, despite encountering some practical challenges in BBF application. Environmentally, the refined BBFs AS and KC showed slightly higher N2O emissions compared to the less refined BBF LFD. However, agronomically, AS exhibited a slightly better crop yield. When used in combination with manure, AS and LFD did not exhibit significant differences in crop yield. Contrary to the hypothesis that refined BBFs would outperform less refined ones environmentally and agronomically, this study rejected that notion. In comparison to minerals, all BBFs demonstrated lower N2O emissions but also slightly reduced crop yields, except for the AS-treated field.

The overall conclusion emphasizes the potential for promoting agricultural circularity by addressing practical issues in LFD application, ensuring BBFs are officially recognized as RENURE materials to legally replace mineral fertilizer, and mitigating the surplus of slurry manure to encourage the utilization and fair pricing of BBF products (link).

6.1.6 Conclusions

Standard production of potatoes includes mineral fertilisation, while production under innovative conditions includes the use of bio-based fertilisers. The most often used mineral fertilisers in potato production are NPK 7 20 30, CAN and UREA. Excessive fertilization leads to environmental pollution, so an innovative scenario in which there is a gradual reduction in fertilizer application is a great solution.

Due to different production conditions, standard and innovative, variable costs also differ. Within the financial analysis of an innovative scenario, one has included costs of digestate application and drone as well as reduction of costs of mineral fertilisers. The cost of the drone has been incorporated as a long-term asset (amortization rate applied in the calculation). The application rate of digestate has

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been determined and harmonized according to the official fertilization management recommendations for the specific crop production and optimal N application.

The total variable costs in standard potato production amount to 3.500,88 €/ha in Croatia and 2.112 €/ha in Belgium, while in innovative production they amount to 4.409,44 €/ha in Croatia and 2.943 €/ha in Belgium. Gross margin calculation for Croatia amounts 1.299,22 €/ha in standard, and 390,65 €/ha in innovative scenario (including machinery cost). In Belgium, gross margin calculation amounts 7.620,75 €/ha in standard and 6.785,75 €/ha in innovative scenario (including machinery cost).

It can be seen from the above that the total variable costs of potato production are higher in the innovative than in the reference case scenario in both countries.

Table 50. Overview of data used as reference to CBA study

Data	**Reference CBA Study**	**Type of data**	**Source of data (Croatia)**	**Source of data (Flanders)**
Baseline info - benefits of potato (yield, early var., late var., unit price)	Table 44	Sector publication	The data of the advisory service of the Ministry of Agriculture	Sector information (stakeholder interaction)
Baseline info – production cost (seed, mineral fertilizers, pesticides, energy, other costs)	Table 44	Sector publication	The data of the advisory service of the Ministry of Agriculture	Sector information (stakeholder interaction)
Baseline info - Total production costs	Table 44	Project produced data	D3.3	D3.3
Baseline info – harvesting cost (rented mechanization, own mechanization, rent land, cost of contract work)	Table 44	Sector publication	The data of the advisory service of the Ministry of Agriculture	Sector information (stakeholder interaction)
Total harvesting costs	Table 44	Project produced data	D3.3	D3.3
Total costs (production cost + harvesting cost)	Table 44	Project produced data	D3.3	D3.3
Baseline info - Gross Margin Calculation (GMC)	Table 44	Project produced data	D3.3	D3.3
Baseline info - Unit price (€/kg) of potato	Table 45	Sector publication	TISUP	
Baseline info - Gross margin calculation (€/ha) (no machinery costs)	Table 45	Project produced data	D3.3	D3.3
Baseline info - Gross margin calculation (€/ha) (including machinery costs)	Table 45	Project produced data	D3.3	D3.3
Composition CAN	Table 46	Sector publication	The data of the advisory service of the Ministry of Agriculture	
Composition UREA	Table 46	Sector publication	The data of the advisory service of the Ministry of Agriculture	
Composition NPK	Table 46	Sector publication	The data of the advisory service of the Ministry of Agriculture	
Fertilizers costs (CAN, UREA, NPK)	Table 46	Sector publication	The data of the advisory service of the Ministry of Agriculture	
Overview of N2C case scenario	Table 43	Project produced data	D2.6	D2.6
Innovative scenario for potato – benefits (yield, early, late, unit price)	Table 47	Sector publication	The data of the advisory service of the Ministry of Agriculture	

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Innovative scenario for potato – production cost (seed, drone, digestate, pesticides)	Table 47	Sector publication	The data of the advisory service of the Ministry of Agriculture	
Innovative scenario – total production cost	Table 47	Project produced data	D3.3	D3.3
Innovative scenario for potato – harvesting cost (rented mechanization, own mechanization, rent land, cost of contract work)	Table 47	Sector publication	The data of the advisory service of the Ministry of Agriculture	
Innovative scenario – total harvesting cost	Table 47	Project produced data	D3.3	D3.3
Innovative scenario - Gross margin calculation	Table 47	Project produced data	D3.3	D3.3
Innovative scenario – unit price (€/kg) of potato	Table 48	Sector publication	TISUP	
Innovative scenario - Gross margin calculation (€/ha) (no machinery costs)	Table 48	Project produced data	D3.3	D3.3
Innovative scenario- Gross margin calculation (€/ha) (including machinery costs)	Table 48	Project produced data	D3.3	D3.3
Recommended fertilization plan (digestate; AS; liquid fraction)	Table 49	Sector publication	The data of the advisory service of the Ministry of Agriculture	

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

Within this research line several different bio-based fertilizers are researched.

Table 51. Overview of the different types of fertilizers that will be evaluated in the CBA assessment

Type of Biobased Fertiliser or soil enhancer	**#LL**	**Substitution for**	**Production process**
Ammonium nitrate (NH_4NO_3)	1	Mineral N fertilizer	Stripping / Scrubbing
Ammonia sulphate $(NH_4)_2SO_4$	2	Mineral N fertilizer	Stripping / Scrubbing
Liquid fraction of digestate	9	Mineral N K fertilizer	
Concentrate	6 & 43	Mineral N fertilizer	Vacuum evaporation / stripping
Struvite	49 & 65	Mineral P fertilizer	
Ammonia concentrate	20	Mineral N fertilizer	Vacuum stripping
Bio-phosphate	22	Mineral P fertilizer	High temperature reductive thermal process

For the CBA assessment on the use of those biobased fertilizers, the technologies will be jointly assessed, indicating that technologies #LL 1, #LL 2, #9, #LL 20, #LL 6 & # LL43 will be discussed first. Next will be the comparison of #LL 22, #LL49 and #LL65.

7.1 Technologies overview

The TRL level of the research technologies varies from 4 up to 9, with the stripping as ammonia-sulphate is already widely implemented in regions with high manure pressure (e.g. Flanders).

The table below shows the TRL level per technology and the agro-typology in which the technology can be implemented. It shows clearly that all of the technologies can be used for the treatment of manure – which will be therefore the main focus of the CBA assessment.

Table 52. Overview of the Agro-typology to which the research and / or generated products can be linked

		LL1	LL2	LL6	LL9	LL43	LL20
TRL Level		7	7	4	7	4 – 5	4
Agro Typology	Pig production					X	
	Poultry production						
	Cattle Farming						
	Open field cultivation of cereals or maize				X	X	
	Open air cultivation of vegetables				X	X	
	Orchards				X		
	Agro-energy systems	X	X			X	
	Animal by-product processing	X	X	X		X	X

The recovery of nitrogen from manure has multiple benefits when comparing it to the current application methods which are shown in table below.

Table 53. Comparison of the main benefits that are obtained when recovering nitrogen from manure

	Current practice	**With N-recovery**
Storage of manure from livestock	NH3 emission to the atmosphere	Reduced NH_3 emissions to the atmosphere
Application of manure on land	High N content in the liquid fraction reduces the volume that can be applied to the field. The excess amount of manure must be treated or exported long distances.	Lower N-content in the resulting manure products. Those products can be managed as fertilizers according to its composition (e.g. new N/P ratio) or further processed (e.g. to recover P)

7.1.1 LL1 + LL2: Ammonium stripping/scrubbing for NH4NO3 or (NH4)2SO4 production

The stripping technology aims 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). The high N concentration gives a potential for recovered AN or AS to be used as a replacement for synthetic N fertilizers. The AN/AS is an end-product of (stripping-)scrubbing technology.

The use of H_2SO_4 for stripping N-loaded air is well-known in Flanders: it can be obtained from scrubbing ammonia (NH_3) rich air from livestock operational units (i.e. stables, drying and composting) or from stripping and scrubbing NH_3 from nitrogen (N) rich waste streams. In the case of air cleaning, the air from animal stables is blown into the system either horizontally (cross-current) or upwards (counter-current) and scrubbed in a scrubbing reactor using sulphuric acid (H_2SO_4). The second option is to first strip NH_3 from N rich waste streams, by adjusting pH and/or temperature levels, to achieve NH3 transfer from liquid to the gaseous phase.

Currently, this product is produced at a large number of livestock farms in Flanders by treating air from livestock operational units. On average 1.5 L of H_2SO_4 is applied to remove 1 kg of NH_3 which results in approximately 30 L of AS, depending on the amount of NH_3 to be removed and the amount of NH_3 that can be in scrubbing water before it is saturated.

For AN the available scale of operations in the livestock sector is still on a pilot scale with the capacity to treat around 30 000 tonnes – 40 000 tonnes of N rich waste stream per year (case study in Flanders, Belgium). The wastewater treatment plant VEAS (Oslo, Norway) produces about 3 000 tonnes of AN (dry weight) per year. The use of AN is not common and currently, it is not recognized as mineral fertilizer in the EU.

This technology is currently applied in livestock operations to recover N from waste streams such as animal manure, digestate and their respective liquid fractions. The selected field is located in central Flanders a region with predominantly sandy soil textures. The field itself also has a sandy texture. The field was part of a mixed cattle-extensive vegetable farm. The main crops on the farm are maize, early potatoes and grassland. Sometimes, spinach, carrots and beans are sown.

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7.1.2 LL9 Liquid fraction of digestate as a substitute for mineral N&K fertilizer

Solid-Liquid separation is the most frequent first step in digestate processing and is usually carried out on-site to reduce transportation costs for disposal, to free up storage space or for further upgrading (such as nutrient extraction). The phase separation leads to a P-rich solid fraction (SF) and an N and K-rich liquid fraction (LF). The SF contains high phosphorous and organic fractions, which is interesting for soil properties and humus formation. It can be further dried, composted, granulated or directly applied to the field as a soil amendment.

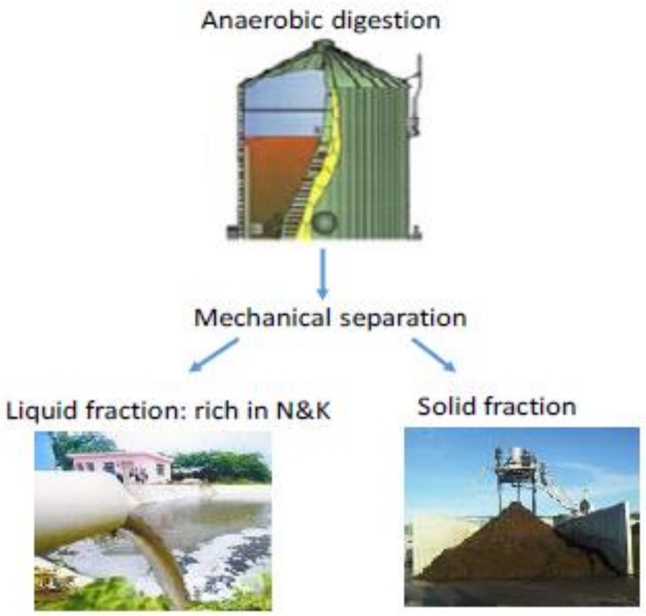

Figure 13. LL9 – Scheme mechanical separation

The most commonly used technologies to mechanically separate the raw digestate into its liquid and solid forms are the screw-press, the centrifuge (decanter) and the belt filter press.

7.1.3 LL6 & LL43 Vacuum evaporation/stripping for the production of nutrient-rich organic fertilizer

LL6: The purpose of vacuum evaporation is to optimize nutrient recovery from the waste streams and produce organic fertilizer with high content of nutrients in small volumes. Vacuum evaporation consists of the boiling of a liquid substrate at negative pressure, at a temperature lower than the typical boiling temperature at atmospheric conditions. Vacuum evaporation is currently applied in various industrial and agro-industrial domains but it is still on trial for livestock effluents.

In general, vacuum evaporation implies boiling a treated (liquid) stream at negative pressure, resulting in a highly concentrated substance (i.e. concentrate) and condensate that can be recycled or used as discharge water. Figure 14 shows a standard unit of the vacuum evaporation process, consisting of an input tank and an evaporator followed by a vacuum circuit.

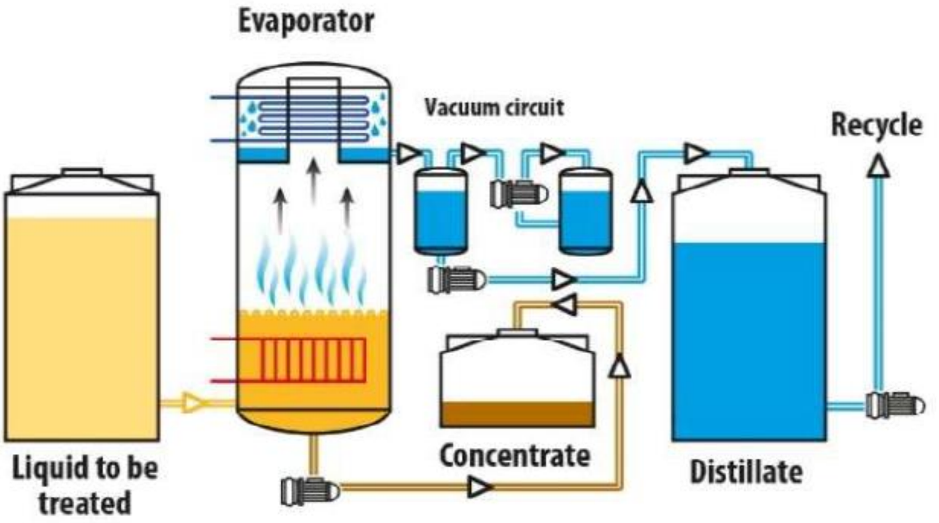

Figure 14. LL6 Technology scheme

Within the H2020 Systemic project, AD plant AMPower has installed two evaporators intending to reduce the water content of their LF of digestate. The LF of digestate (NK-rich) is sent to the evaporator without prior acidification pre-treatment.

Meaning, that evaporation leads to the production of N-rich condensate (so-called ammonia water) and up-concentrated LF of digestate. Both products might have the potential to be used as recycled fertilizers in crop cultivation.

Also, **LL43** uses the system of vacuum stripping, though with a focus on pig manure. This technique aims to process all fractions of the pig manure into separate fertilizer products for N, P and K. This is to ensure optimal circular use of the different nutrients, suitable for precision fertilizing application techniques. These organic-based fertilizers will replace mineral fertilizers.

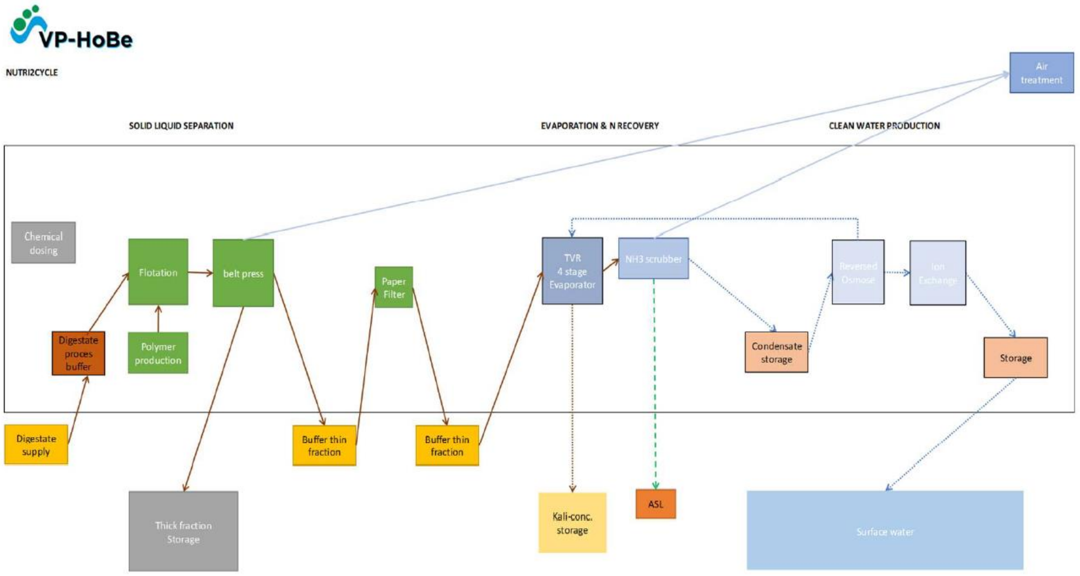

Figure 15. LL43 Technology scheme

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The pig manure first goes through the biogas production (it is subjected to anaerobic co-digestion during which biogas and digestate are produced), the digestate is separated, the thick fraction is dried to 90% dry matter for further processing to organic fertilizer pellets, the fluid fraction is concentrated by the evaporation unit. N is recovered using N-stripping technology and the K-concentrate remains after evaporating water. The water is clean and can return to surface water. N, P and K can be used as separate fertilizing products.

Because the N, P and K nutrients are recovered in different fertilizing products they can be applied separately using techniques for precision fertilization. This will lead to more nutrient efficiency and will reduce the need for mineral fertilizers.

7.1.4 LL20 Low-temperature ammonium-stripping using vacuum

This technology is based on the evaporation of ammonia in vacuum conditions. The aim is the recovery of ammonia from livestock slurry and obtaining an ammonia salt that can be reused as a fertiliser. It can be applied directly to the liquid fraction of raw livestock manure, to avoid ammonia gas emissions to the atmosphere, or as a subsequent step of an anaerobic digestion process.

Preliminary assays were performed in a lab-scale rotovapor. Each batch experiment had 0.5 L of raw pig slurry fed to a 1 L spherical boiling flask. Once the optimum pH value was determined, the effect of the temperature was evaluated by performing an assay at 30°C. Each batch lasted for 6 h.

After determining the optimum conditions at the lab scale, assays were performed in a 30 L pilot system, and around 15 tonnes/year of raw or digested livestock manure can be treated in a discontinuous mode.

This technology has been tested at a pilot scale in the IRTA facilities (Caldes de Montbui, Barcelona, Spain).

The pilot system was operated at 45 C and 20 kPa, with 10 L of raw pig slurry or digestate with different initial ammonia concentrations and an initial pH value of 11, to determine its relation with the ammonia evaporation flux. The duration of each batch was 6 hours. In this pilot system, the N-NH4+ removal efficiency with the different ammonia concentration pig slurries achieved between 54 % and 63 % in the 6 hours assays. Ammonia flux increased in linear relation when increasing ammonia initial concentration. The maximum amount of ammonia capable of being absorbed with the water trap was 2441 mg/L while 87422 mg/L were absorbed in the acid trap.

A second pilot system at the farm scale started operation in January 2020 with some changes in conditions. Duration of batches is 3 hours and operation temperature 40 C. The pH value of the pig slurry is modified up to 11 with Ca(OH)2 once fed to the reactor. Following the evaporator, a water trap is placed to catch NH3 and an acidic trap to minimise atmospheric emissions. Liquid/solid samples (7 samples) and gasses emission samples (4 samples) will be taken (sample point number 8). This way the mass and nutrients (N, P and K) balance of the proposed system could be calculated. Pig slurry and the different streams of the system will be characterised physiochemically with appropriate parameters.

Taking into account the preliminary results obtained at lab and pilot scale, vacuum evaporation shows to be an interesting alternative for ammonia recovery from livestock manure. Currently, with the results of the pilot plant (30 L reactor), around 15 tonnes/year of raw or digested livestock manure

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can be treated in a discontinuous mode (6 hours per batch). It is expected to achieve a higher capacity of treatment thanks to the work that is currently being performed in the improvement of the design to increase the area-volume relation of the system. Further improvement of the area-volume relation of the system and scale-up will allow for a higher capacity of treatment.

7.2 Products overview

The table below shows an overview of the products generated by the applied technologies. It will be those end products that can be used a substitute for the mineral fertilizers.

Table 54. Overview of the products generated by the applied technologies

#LL	Technology	Input	End product(s)			
1	Scrubbing / stripping HNO_3	Liquid fraction of digestate (NK rich)	Up concentrated LF (K-rich)	Ammonia nitrate		
2	Scrubbing / stripping H_2SO_4	Liquid fraction of digestate (NK rich)	Up concentrated LF (K-rich)	Ammonia sulphate		
6	Vacuum / stripping	Liquid fraction of digestate (NK rich)	N-rich condensate (ammonia water)	concentrated LF (K-rich)		
9	Separation	Digestate	Liquid fraction of digestate (NK rich)	Thick fraction of digestate (P rich)		
43	Vacuum / stripping	Pig manure	Ammonium sulphate (N rich)	Up concentrated LF (K-rich)	Thick fraction (P-rich)	Dischargeable water
20	Vacuum stripping (lactate acid)	Liquid fraction of Livestock slurry	Ammonia lactate	Solid fraction	Treated liquid fraction	

The table below gives an overview of the composition of the different recovered biobased fertilizers (BBF's), as taken from the overview of the collected data from the Nutri2Cycle project (D2.6 – average in numbers from 2019 and 2020).

Table 55. Overview of the composition of the recovered biobased fertilizers

#LL	Technology	Product	Composition (kg/T FM) (Averages)			
			NO_3-N	NH_4-N	P_2O_5	K_2O
1	Scrubbing / stripping (HNO_3)	Ammonium nitrate	46.7	47.7	0	0
2	Scrubbing / stripping (H_2SO_4)	Ammonium sulphate	0	38.6	0.15	27
6	Vacuum / stripping	Ammonia water	0.035	118	0	0.002
9	Separation	LF digestate	0.01	3.01	3.01	1.82
20	Vacuum stripping (Lactate acid)	Ammonium lactate	0.1	12.2	0	58

7.3 Financial/economic analysis – Reference scenario

The economic assessment of the different generated fertilizers will be done for the production of maize, which importance is evident in its wide usability worldwide. Maize is a plant that has great needs for plant nutrients because in the short vegetation period it produces large yields of organic matter.

Fertilisation of maize depends on soil fertility, planned yields and production conditions. Fertilisation shall be adapted to production conditions, economically viable and environmentally friendly. Of great importance in the choice of fertiliser is the price, which should be affordable to different stakeholders.

Table 56. Recommended fertilization plan for standard maize production in Croatia (2019) (link)

Recommended fertilization Maize with only mineral fertilizers (Croatia 2019)					**Applied fertilizers kg / ha**				**Fertilizer costs**
Type of fertilizer	Kg N / kg	kg P2O5 / kg	kg K2O / kg	€/kg	**Total kg fertilizers**	**N**	**P2O5**	**K2O**	**€/ha**
CAN	0,27			0,21	**180**	48,6			**37,8**
UREA	0,46			0,3	**100**	46			**30**
NPK	0,07	0,2	0,3	0,5	**450**	31,5	90	135	**225**
NPK	0,15	0,15	0,15	0,32	**150**	22,5	22,5	22,5	**48**
Total					**880**	**148,6**	**112,5**	**157,5**	**340,8**

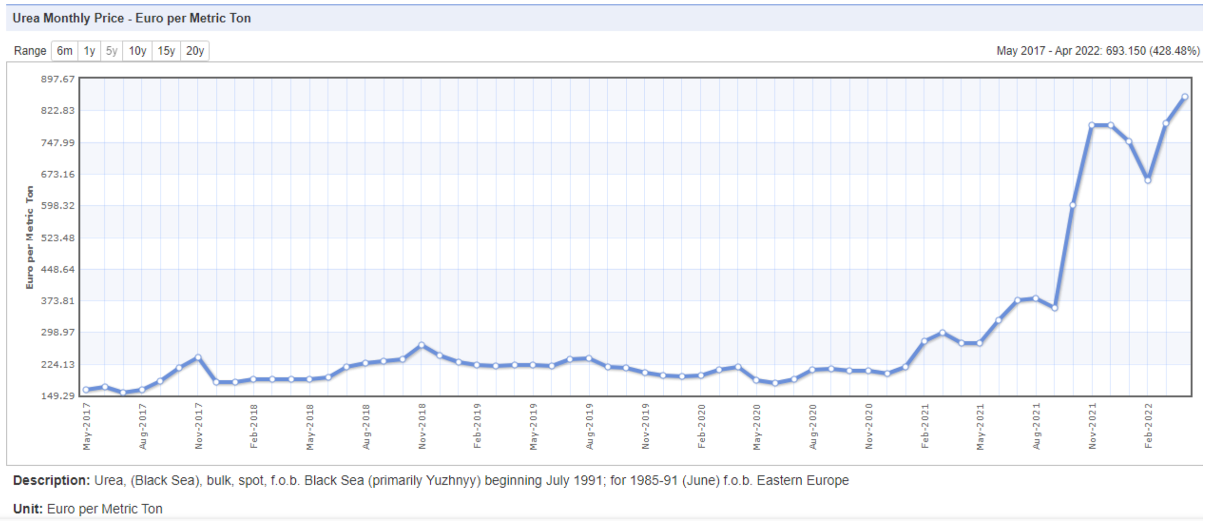
For **Flanders** a similar type of fertilisation is envisioned. The amount of fertilizer applied on arable land for maize production is in 2019 limited by legislation to **150 kg $N_{effective}$ / ha.year** for those areas with a non-sandy soil structure (link).

For mineral fertilizers 100 % of the N-fertilizer applied is assumed to be "effective", meaning that each kg of applied N has to be taken into account. Where as for the applied animal manure (slurry) only 60 % is assumed to be effective and for the thick fraction of manure (incl. slow release fertilizers) only 30 % is defined as "effective". Anyway, the application of animal manure can never exceed 170 kg N/ha.year. The limit of P-fertilisation is 100 kg/ha.year. The recommended fertilization for Maize in Flanders is shown in the following table.

Table 57. Recommended fertilization Maize in Flanders on sandy soil (link, link)

		Recommended fertilization Maize (Belgium 2019 – sandy soil (Kempen)				
		Applied fertilizers kg / ha				**Fertilizer costs**
Type of fertilizer	€/kg	**Total kg fertilizers**	**Neff**	**P2O5**	**K2O**	**€/ha**
Manure (or manure derived products)	0	**35000**	97	50	165	**0**
CAN	0,21	**175**	47			**36,75**
KCl	0,19	**250**			100	**46,25**
Total		**460**	**144**	**50**	**265**	**83**

It shows from the above (Table 57) that when using only mineral fertilizers the costs for fertilizers in 2019 represented about 30 – 35 % of the total costs, which is a very significant part. The price for those mineral fertilizers have increased significantly since the end of 2021, what makes the impact on the costs significantly higher. The figure below shows the evolution of the price of urea (€ / MT) in Eastern Europe. It shows that the price was more or less stable from 2017 until 2019 (around 215 € / ton), where in July / August it was already at 350 € / ton and in December 2021 it topped at 780 € / ton. This is an increase of more than 360 % in 2 years' time.



Description: Urea, (Black Sea), bulk, spot, f.o.b. Black Sea (primarily Yuzhnyy) beginning July 1991; for 1985-91 (June) f.o.b. Eastern Europe

Unit: Euro per Metric Ton

Figure 16. Evolution market price for urea in Eastern Europe (link)

Given the high (and increasing) costs for mineral fertilizers, farmers are looking for alternatives, which they can find in using raw manure or other manure derived products. In Flanders the main fertilizer applied is the application of raw manure (region with a high manure density), but in order to maximize the yield per hectare, also mineral fertilizers will be added.

7.3.1 N2C case scenario

The CBA assessment is done by replacing the regular N-fertilizer by the innovative N-fertilizers. The following scenarios will be assessed:

Scenario 1: replacement with ammonium nitrate
Scenario 2: replacement with ammonium sulphate
Scenario 3: replacement with ammonia water
Scenario 4: replacement with liquid fraction of digestate (LF digestate)
Scenario 5: replacement with ammonium lactate

The aim is to always achieve the recommended amount of fertilizers applied per hectare of maize cultivated. That means that the substitution of the mineral N-fertilizer with either one of the innovative N-fertilizers (Biobased Fertilizers) does not assure the complete non-use of mineral fertilizers: when required to apply the total recommended amount of fertilizers mineral fertilizers can be added.

The table below (Table 58) shows the assessment for the manure extensive region of Croatia. One can notice that for Scenario 4 (LF digestate) and Scenario 5 (ammonium lactate) there is an addition of mineral N-fertilizer (CAN). This is due to the fact that for scenario 4 the P2O5 content of the LF digestate was the limiting factor, where for scenario 5 this was the K2O content of the ammonium lactate. In both those latter cases CAN fertiliser is than applied in order to meet the total N-fertilizer recommendation.

Table 58. Assessment of the different scenarios for a manure extensive region

Extensive region					
	Fertilizers				
		kg/ha	kg N/ha	kg P2O5/ha	kg K2O /ha
Reference	CAN	180	48,6		
	UREA	100	46		
	NPK	450	31,5	90	135
	NPK	150	22,5	22,5	22,5
	TOTAL	**880**	**149**	**113**	**158**
Scen 1	**Ammonium Nitrate**	1574	148,6	0,0	0,00
	Triple super phosphate	245		112,5	
	KCl	263			157,50
	Total	**2081**	**149**	**113**	**158**
Scen 2	**Ammonium Sulphate**	3852	149	0,6	103,82
	Triple super phosphate	243		111,9	
	KCl	89			53,68
	Total	**4185**	**149**	**113**	**158**
Scen 3	**Ammonia water**	1259	149	0,0	0,00
	Triple super phosphate	245		112,5	
	KCl	262			157,50
	Total	**1766**	**149**	**113**	**158**
Scen 4	**LF digestate**	37438	113	**112,5**	67,95
	CAN	132	36		
	Triple super phosphate	0		0,0	
	KCl	149			89,55
	Total	**37719**	**149**	**113**	**158**
Scen 5	**Ammonium lactate**	2716	33	0,0	**158**
	CAN	427	115		
	Triple super phosphate	245		112,5	
	KCl	0			0,00
	Total	**3387**	**149**	**113**	**158**

A similar evaluation was performed for a manure intensive region. The reference is the recommended fertilization for 1 ha of arable land (maize cultivation) in a region with a sandy soil (the Kempen). The table below shows the combination of parcels that would result in the 5 scenarios.

In all scenarios – except the 4th scenario – the use of manure as a fertilizer is maintained as a base. The other fertilizers are adjusted to the baseload of nutrients provided by base-load of manure. As in this region the phosphorous is the "limiting component" for the amount of manure that can be applied, none of the scenarios include dosing mineral P-fertilizer. Only for the 4th scenario a different approach was required, as in this scenario the phosphorous load of the manure would prohibit the application of LF digestate as an additional fertilizer. Therefore, this scenario does not include the application of raw manure on the field.

Table 59. Assessment of the different scenarios for the region of Flanders

Intensive region - Sand soil					
	Fertilizers				
		kg/ha	kg N/ha	kg P2O5/ha	kg K2O /ha
Reference	CAN	175	47		
	Manure	35000	97	50	165
	KCl	250			100
	TOTAL	**35425**	**144**	**50**	**265**
Scen 1	**Ammonium Nitrate**	498	47	0,0	0,00
	Manure	35000	97	50	165
	Triple super phosphate	0		0,0	
	KCl	167			100,00
	Total	**35665**	**144**	**50**	**265**
Scen 2	**Ammonium Sulphate**	1218	47	0,2	32,84
	Manure	35000	97	50	165
	Triple super phosphate	0		0,0	
	KCl	112			67,16
	Total	**36330**	**144**	**50**	**265**
Scen 3	**Ammonia water**	398	47	0,0	0,00
	Manure	35000	97	50	165
	Triple super phosphate	0		0,0	
	KCl	167			100,00
	Total	**35565**	**144**	**50**	**265**
Scen 4	**LF digestate**	16639	50	**50,0**	30,20
	CAN	348	94		
	Manure	**0**	0	0	0
	Triple super phosphate	0		0	
	KCl	391			234,80
	Total	**17378**	**144**	**50**	**265**
Scen 5	**Ammonium lactate**	1724	21	0,0	**100**
	CAN	96	26		
	Manure	35000	97	50	165
	Triple super phosphate	0		0,0	
	KCl	0			0
	Total	**36820**	**144**	**50**	**265**

7.4 Cost Benefit Analysis – Innovative scenario

Based on the application of the mineral fertilizers (as a reference) and their substitution with innovative Biobased Fertilizers (see table above) a cost benefit assessment could be performed. The issue is though that there is no “market-price” for the Biobased Fertilizers yet. Given this fact it is decided to do the “back-calculation” in which it is calculated what the maximum price of the Biobased Fertilizers is so that there is no increase of the total costs per hectare (€/ha).

In order to perform the CBA, the following assumptions are made:

- The yield of the crops remains unchanged and is independent of the type of biobased fertilizer used;
- There is no additional labour required for the application of the biobased fertilizers;
- There is no investment in new equipment required for the application of the bio-based fertilizers;

- The additional required transport includes also additional labour time for doing the transport;
- All other costs per hectare (seeds, pesticides, mechanization, insurances, etc.) remain unchanged.

The results of the CBA for the manure extensive region is shown in the table below (based on price data from 2019).

Table 60. Economic evaluation of the different scenarios for maize production in a manure extensive region

Extensive region								
	Fertilizers				Transport 2 €/ton	Total Costs	Benefit compared to reference	Max cost BBF/kg
		€/kg	kg/ha	**€/ha**	€/ha	€/ha	€/ha	€/kg
Reference	CAN	0,2	180	**37,8**				
	UREA	0,3	100	**30**				
	NPK	0,5	450	**225**				
	NPK	0,3	150	**48**				
	TOTAL		**880**	**340,8**	**2**	343		
Scen 1	**Ammonium Nitrate**		1574	**0**				
	Triple super phosphate	0,3	245	**73,4**				
	KCl	0,2	263	**52,5**				
	Total		**2081**	**126**	**4**	130	213	0,135
Scen 2	**Ammonium Sulphate**		3852	**0**				
	Triple super phosphate	0,3	243	**73,0**				
	KCl	0,2	89	**17,9**				
	Total		**4185**	**91**	**8**	99	243	0,063
Scen 3	**Ammonia water**		1259	**0**				
	Triple super phosphate	0,3	245	**73,4**				
	KCl	0,2	262	**52,5**				
	Total		**1766**	**126**	**4**	129	213	0,169
Scen 4	**LF digestate**		37438	**0**				
	CAN	0,2	132	**26,5**				
	Triple super phosphate	0,3	0	**0,0**				
	KCl	0,2	149	**29,9**				
	Total		**37719**	**56**	**75**	132	211	0,006
Scen 5	**Ammonium lactate**		2716	**0**				
	CAN	0,2	427	**85,3**				
	Triple super phosphate	0,3	245	**73,4**				
	KCl	0,2	0	**0,0**				
	Total		**3387**	**159**	**7**	165	177	0,065

The numbers shown in blue in the table above are the most important numbers to evaluate the results. Those numbers indicate the maximal price a farmer should pay for the acquisition of the biobased fertilizer. If he would pay more than this indicated price, he would loose money compared to the reference situation, as this would mean that he is paying more for the same level of fertilization.

The results for the assessment for the manure intensive region (reference region the Kempen – sandy soil; price data from 2019) is in the table below.

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

Table 61. Economic evaluation of the different scenarios for the production of maize in a manure intensive region

Intensive region - Sand soil								
	Fertilizers				Transport 4 €/ton	Total Costs	Benefit compared to reference	Max cost BBF/kg
		€/kg	kg/ha	€/ha	€/ha	€/ha	€/ha	€/kg
Reference	CAN	0,21	175	36,75				
	Manure	0,00	35000	0				
	KCl	0,19	250	46,25				
	TOTAL		35425	83	142	225		
Scen 1	Ammonium Nitrate		498	0				
	Manure	0	35000	0				
	Triple super phosphate	0,3	0	0,0				
	KCl	0,2	167	33,3				
	Total		35665	33	143	176	49	0,098
Scen 2	Ammonium Sulphate		1218	0				
	Manure	0	35000	0				
	Triple super phosphate	0,3	0	0,0				
	KCl	0,2	112	22,4				
	Total		36330	22	145	168	57	0,047
Scen 3	Ammonia water		398	0				
	Manure	0	35000	0				
	Triple super phosphate	0,3	0	0,0				
	KCl	0,2	167	33,3				
	Total		35565	33	142	176	49	0,123
Scen 4	LF digestate		16639	0				
	CAN	0,2	348	69,5				
	Manure	0	0	0,0				
	Triple super phosphate	0,3	0	0,0				
	KCl	0,2	391	78,3				
	Total		17378	148	70	217	7	0,000
Scen 5	Ammonium lactate		1724	0				
	CAN	0,2	96	19,1				
	Manure	0	35000	0,0				
	Triple super phosphate	0,3	0	0,0				
	KCl	0,2	0	0,0				
	Total		36820	19	147	166	58	0,034

7.4.1 Impact of price variations

As indicated above, the price per kg of the mineral fertilizers has increased significantly lately. Therefore, an assessment was done to have an idea of those “market fluctuations” on the CBA assessment. Considering all other parameters as constant (i.e. the amount of fertilizer to be used, type of crop, yield per ha, cost for transport, etc.), the following price fluctuations were taken into account:

- Extreme low: the price of the fertilizers drop with 25 % compared to the price of 2019
- Low: the price of fertilizers drop with 10 % compared to the price of 2019
- Average: reference with data of 2019
- High: the price of the fertilizers increases with 200% (reference situation 2022).
- Extreme high: the price of the fertilizers increases with 100% compared to the price of 2022

Using the same methodology as before, it is then calculated what the maximum price for the recovered nutrients can be in order to have the same fertilizer cost per ha as in the reference scenario.

The tables below (Table 62 & 63) show the results for the price impact on manure intensive or extensive regions.

Table 62. Assessment of the impact of variations in the price of mineral fertilizers for a manure extensive region

EXTENSIVE REGION Variable cost / ha		**EXTREME LOW**	**LOW**	**AVERAGE (2019)**	**HIGH (2022)**	**EXTREME HIGH**
		-25%	**-10%**	**Ref**	**2019 +200 %**	**+100% of 2022**
		€/kg	**€/kg**	**€/kg**	**€/kg**	**€/kg**
Reference	CAN	0,1575	0,189	0,21	0,63	1,26
	UREA	0,225	0,27	0,3	0,9	1,8
	NPK	0,375	0,45	0,5	1,5	3
	NPK	0,24	0,288	0,32	0,96	1,92
	Cost / ha	**257**	**308**	**343**	**1024**	**2047**
Scen 1	Triple super phosphate	0,225	0,27	0,3	0,9	1,8
	KCl	0,15	0,18	0,2	0,6	1,2
	Ammonium nitrate	0,101	0,121	0,135	0,408	0,818
Scen 2	Triple super phosphate	0,225	0,27	0,3	0,9	1,8
	KCl	0,15	0,18	0,2	0,6	1,2
	Ammonium Sulphate	0,047	0,057	0,063	0,193	0,388
Scen 3	Triple super phosphate	0,225	0,27	0,3	0,9	1,8
	KCl	0,15	0,18	0,2	0,6	1,2
	Ammonia Water	0,127	0,152	0,169	0,511	1,023
Scen 4	CAN	0,15	0,18	0,2	0,6	1,2
	Triple super phosphate	0,225	0,27	0,3	0,9	1,8
	KCl	0,15	0,18	0,2	0,6	1,2
	LF Digestate	0,0037	0,0049	0,0056	0,021	0,044
Scen 5	CAN	0,15	0,18	0,2	0,6	1,2
	Triple super phosphate	0,225	0,27	0,3	0,9	1,8
	KCl	0,15	0,18	0,2	0,6	1,2
	Ammonium Lactate	0,048	0,059	0,065	0,199	0,401

Table 63. Assessment of the impact of variations in the price of mineral fertilizers for a manure intensive region

INTENSIVE REGION Cariable Cost / ha		**EXTREME LOW**	**LOW**	**AVERAGE (2019)**	**HIGH (2022)**	**EXTREME HIGH**
		-25%	**-10%**	**Ref**	**2019 +200 %**	**+100% of 2022**
		€/kg	**€/kg**	**€/kg**	**€/kg**	**€/kg**
Reference	CAN	0,1575	0,189	0,21	0,63	1,26
	Manure	0	0	0,00	0	0
	KCl	0,13875	0,1665	0,19	0,555	1,11
	Cost / ha	**204**	**216**	**224,7**	**391**	**640**
Scen 1	Manure	0	0	0	0	0
	Triple super phosphate	0,225	0,27	0,3	0,9	1,8
	KCl	0,15	0,18	0,2	0,6	1,2
	Ammonium nitrate	0,073	0,088	0,098	0,297	0,597
Scen 2	Manure	0	0	0	0	0
	Triple super phosphate	0,225	0,27	0,3	0,9	1,8
	KCl	0,15	0,18	0,2	0,6	1,2
	Ammonium Sulphate	0,034	0,042	0,047	0,146	0,296
Scen 3	Manure	0	0	0	0	0
	Triple super phosphate	0,225	0,27	0,3	0,9	1,8
	KCl	0,15	0,18	0,2	0,6	1,2
	Ammonia Water	0,092	0,111	0,123	0,373	0,747
Scen 4	CAN	0,15	0,18	0,2	0,6	1,2
	Manure	0	0	0	0	0
	Triple super phosphate	0,225	0,27	0,3	0,9	1,8
	KCl	0,15	0,18	0,2	0,6	1,2
	LF Digestate	0,0014	0,0008	0,0004	-0,007	-0,019
Scen 5	CAN	0,15	0,18	0,2	0,6	1,2
	Manure	0	0	0	0	0
	Triple super phosphate	0,225	0,27	0,3	0,9	1,8
	KCl	0,15	0,18	0,2	0,6	1,2
	Ammonium Lactate	0,025	0,030	0,034	0,108	0,219

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

The negative values show that for the scenario where LF digestate is replacing manure it becomes impossible to have a positive (economic) impact, as due to the increase of the cost of CAN (which is required in higher amounts when applying LF digestate) the cost/ha will always be above the reference scenario.

7.4.2 Comparative analysis of innovative scenario and published research

The Cost-Benefit Analysis (CBA) evaluates the replacement of traditional N-fertilizers with innovative N-fertilizers while ensuring the recommended fertilizer amount per hectare of maize cultivation is maintained. This substitution does not eliminate mineral fertilizers entirely; they may be added if necessary to meet the total recommended amount.

The analysis reveals that the ammonia water can be the "most expensive" biobased N-fertilizer, priced at 0.169 €/kg for manure-extensive regions and 0.123 €/kg for manure-intensive regions. Ammonium nitrate follows closely at 0.135 €/kg in manure-extensive regions and 0.098 €/kg in manure-intensive regions. In contrast, the "least expensive" biobased N-fertilizer is the liquid fraction of digestate, costing 0.0056 €/kg for manure-extensive regions and 0.0004 €/kg for manure-intensive regions.

Comparing maximum market prices between regions reveals significant variations, particularly in Croatia, a region facing nutrient shortages. Prices for ammonium nitrate, ammonium sulphate, and ammonium water in Croatia can be 38 %, 34 %, and 37 % higher, respectively, compared to Flanders, a region with a nutrient surplus. Notably, ammonium lactate could be up to 91 % more expensive in Croatia.

It is not easy to compare those results with published articles. Many research studies are focused to finding the most effective NRR technologies and processes to from different streams in order to replace the synthetically derived fertilizers, though little focus on the economic impact that it might have on the end-users of the biobased fertilizers. On top, by doing the assessment through the back-calculation, it does not entail a concrete case study.

The research of Vaneeckhaute et al. (2013) does work with 21 different fertilization scenarios for the fertilization of maize on non-sandy soils. This research makes an evaluation of both the economic and ecologic impact of using biobased fertilizers and shows that the maximal economic benefit (i.e. lower cost of 82€/ha) for the farmer was reached when using membrane filtration concentrates. However, the results are not directly comparable with the results from this study, as in the research the “total” economic cost is considered (taking into account for example the production and packaging cost of the mineral fertilizer etc.). On top, this study considers that the farmer would be payed for using the biobased fertilizers (e.g. for the liquid fraction (5.3 €/ton).

7.4.3 Conclusions

The tables above give an overview of what the farmers could pay for the recovered fertilizers without impact on the economic balance of their production. This means that if they can buy the biobased fertilizers for a price below this indicated maximum values, they will have a financial benefit for their production compared to the reference scenario.

It can also be concluded that the “most expensive” biobased N-fertilizer would be the ammonia water (0.169 €/kg for manure extensive regions; 0.123 €/kg for manure intensive regions), followed by ammonium nitrate (0.135 €/kg in manure extensive regions; 0.098 €/kg for manure intensive regions). The “least expensive” biobased N-fertilizer would be the liquid fraction of digestate for both regions (0.0056 €/kg for manure extensive regions; 0.0004 €/kg for manure intensive regions).

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

When comparing the maximum market price between regions it shows that for Croatia (i.e. the region with the shortage in nutrients) the market price can be significantly higher than in Flanders (i.e. the region with the nutrient surplus). For ammonium nitrate, ammonium sulphate and ammonium water the price in Croatia can be 38 %, 34 % and 37 % higher respectively. For ammonium lactate the price could be up to 91 % higher.

Table 64. Overview of data used as reference to CBA study

Data	**Reference CBA Study**	**Type of data**	**Source of data (Croatia)**	**Source of data (Flanders)**
Overview of the products generated by the applied technologies	Table 51	Project produced data	D2.6	D2.6
Overview of agro-typology	Table 52	Project produced data	D2.6	D2.6
Comparison of the main benefits that are obtained when recovering nitrogen from manure	Table 53	Project produced data	D2.6	D2.6
Overview of the products generated by the applied technologies	Table 54	Project produced data	D2.6	D2.6
Composition of ammonium nitrate	Table 55	Project produced data	D2.3	D2.3
Composition of ammonium sulphate	Table 55	Project produced data	D2.3	D2.3
Composition of ammonia water	Table 55	Project produced data	D2.3	
Composition of LF digestate	Table 55	Project produced data	D2.3	
Composition of ammonium lactate	Table 55	Project produced data	D2.3	
Composition CAN	Table 56	Sector publication	The data of the advisory service of the Ministry of Agriculture	
Composition UREA	Table 56	Sector publication	The data of the advisory service of the Ministry of Agriculture	
Composition NPK	Table 56	Sector publication	The data of the advisory service of the Ministry of Agriculture	
Composition NPK	Table 56	Sector publication	The data of the advisory service of the Ministry of Agriculture	
Fertilizers costs (CAN, UREA, NPK)	Table 56	Sector publication	The data of the advisory service of the Ministry of Agriculture	
Composition of manure	Table 57	Sector publication		Web research
Composition of CAN	Table 57	Sector publication		Web research
Composition of KCl	Table 57	Sector publication		Web research
Assessment of the different scenarios for manure extensive region	Table 58	Project produced data	D3.3	D3.3
Assessment of the different scenarios, Flanders	Table 59	Project produced data	D3.3	D3.3
Economic evaluation, maize production in manure extensive region	Table 60	Project produced data	D3.3	D3.3

Economic evaluation, maize production in manure intensive region	Table 61	Project produced data	D3.3	D3.3
Assessment of the impact of variations in the price of mineral fertilizers for a manure extensive/intensive region	Table 62 & 63	Project produced data	D3.3	D3.3

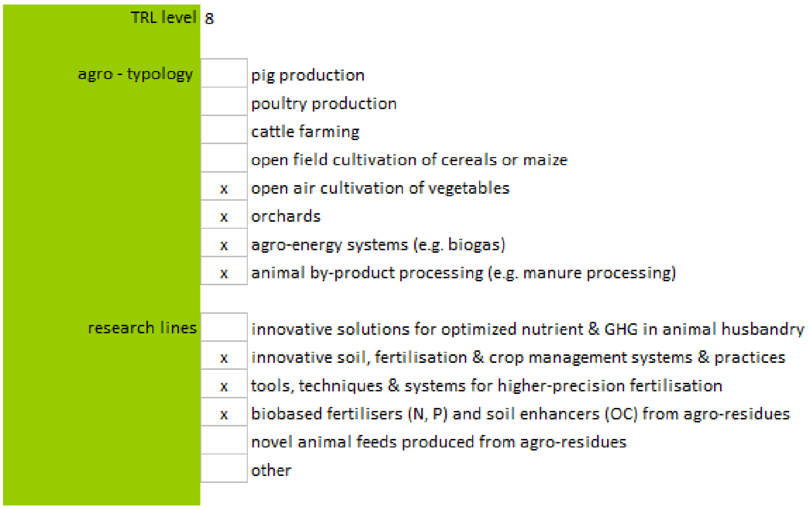
7.5 LL22 BIO-PHOSPHATE: high temperature reductive thermal process recovery of concentrated phosphorus

The Bio-Phosphate system aims to substitute and replace the high cadmium and uranium content non-renewable and imported rock phosphates based mineral fertilizers with a natural, fully safe, renewable and high efficient organic innovative fertilizer in economical high nutrient concentration for less cost while mitigating environmental contamination and GHG emissions.

The only phosphate mineral natural resource with high phosphorus concentration on the industrial and economically available scale is the apatite mineral, which is having two major natural forms, mineral phosphates and bio-origin animal bones.

The scale of operations:

Current scale: 2,000 t/y throughput capacity with 1,200 t/y Bio-Phosphate production with 30 % P2O5 concentration. BIO-NPK-C formulation as of user need.
Foreseen scale 2019/2020: 20,800 t/y throughput capacity/unit with 12,500 t/y Bio-Phosphate production with 30 % P2O5 concentration. BIO-NPK-C formulation made as of specific organic and low input farming user need.
Foreseen scale 2020 - 2025: ten projects targeted in the EU, USA and Australia with 125,000 t/y Bio-Phosphate productions with > 30% P2O5 concentration. BIO-NPK-C formulation made as of specific organic and low input farming user need.
Foreseen scale 2025 - 2030: at least additional 20 - 25 projects targeted in the EU, USA and Australia with additional 250,000 t/y Bio-Phosphate production with 30 % P2O5 concentration. BIO-NPK-C formulation made as of specific organic and low input farming user need. The estimated total production volume by 2030 is ≈+400,000 t/y Bio-Phosphate/year.



TRL level	8	
agro - typology		pig production
		poultry production
		cattle farming
		open field cultivation of cereals or maize
	x	open air cultivation of vegetables
	x	orchards
	x	agro-energy systems (e.g. biogas)
	x	animal by-product processing (e.g. manure processing)
research lines		innovative solutions for optimized nutrient & GHG in animal husbandry
	x	innovative soil, fertilisation & crop management systems & practices
	x	tools, techniques & systems for higher-precision fertilisation
	x	biobased fertilisers (N, P) and soil enhancers (OC) from agro-residues
		novel animal feeds produced from agro-residues
		other

Figure 17. LL22 Technology TRL, agro-typology and research lines

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

7.5.1 Technology background

Potato production

Potato (*Solanum tuberosum*) requires a well-drained, well-aerated, porous soil with a pH of 5 to 6. This crop is grown in a 3 or more year rotation with other crops such as maize, beans and alfalfa (link).

Fertilizer requirements are relatively high and it is best to apply organic fertilisers in basic fertilisation during autumn. Manure is most often used organic fertiliser, and it is ploughed in autumn-winter fertilisation in the amount of 20-30 t/ha. To ensure optimal yields, the application of mineral fertilisers should provide: 100-140 kg N/ha, 100-120 kg P2O5/ha, 160-200 kg K2O/ha. In addition to manure, it is necessary to apply mineral NPK fertilisers with a pronounced content of phosphorus and potassium in the basic fertilisation (link).

In Croatia, 7.000 ha of agricultural areas was used for potato production, and 135.000 tons of potatoes were produced in 2019. In 2020, agricultural areas used for potato production remained the same (7.000 ha), while the production increased and amounted to 152.000 tons.

In 2020, potatoes were cultivated on 1.7 million hectares in the EU, on which 54 million tonnes of crops were produced. This corresponded to an estimated 1.7 % of all arable land in the EU. This share was much higher in the Netherlands (16.3 % of all arable land), Belgium (11.3 %) and Malta (7.5 %).

Belgium's share in total EU's harvested production of potatoes in 2020 amounted to 7,2 %, and the share of **Croatia** was 0,4 % (link).

The value at basic prices of the raw potatoes (including seed potatoes) produced in **Croatia** in 2020 was an estimated 31.9 million €. In Belgium, more than 3.500 farmers produce nearly 100.000 hectares of potatoes at an estimated value of €350 and 550 million € ($394 and $620 million). With the aim to improve quality and quantity, Belgian farmers continue to invest in sustainable cultivation practices and logistics (link).

The average price of potatoes in **Croatia** in 2022 is 0,49 €/kg, while in **Belgium** price for 1 kg of potatoes amounts to 1,36 € (range from 0,80 to 2,99 €) (link).

Food grade animal bones

Disrupted nutrient recycling is a serious problem for Europe and all over the world. Phosphorus (P) and nitrogen (N) are lost across environmental media during food production or are wasted instead of being used for plant nutrition. Therefore, phosphorus recovery from agricultural and food industrial by-product streams is a critically important key priority. Phosphorus recovery from food grade animal bone by-products have been researched since 2002 and a specific zero emission autothermal carbonization system, called 3R, has been developed on an economical industrial scale, providing the animal bone char product (ABC) as output. Different animal bone by-products were tested under different conditions at 400 kg/h throughput capacity in the continuously operated 3R system. Different material core treatment temperatures (between >300 °C and < 850 °C) were combined with different residence times under industrial productive processing conditions. It was demonstrated that material core treatment temperature < 850 °C with 20 min residence time is necessary to achieve high-quality ABC with useful agronomic value. The output ABC product has concentrated > 30 % phosphorus pentoxide (P2O5), making it a high-quality innovative fertilizer (link).

Biological apatite is an inorganic calcium phosphate salt. It is also a main inorganic component of biological hard tissues such as bones (link). The majority of P (85 – 88 %) exists as bone P in the body

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of vertebrates (link). The P content of bovine and poultry bone is > 10.5% on a dry weight basis (link, link). Other animal by-products have far lower phosphorus content than bone grist. For example, the phosphorus content of liquid pig manure, with 2 – 10 % dry matter content, is 0.20 – 1.25 % while the solid pig manure with 20 – 30 % dry matter content has 1.6 – 5.08 % P-content (link).

Biochar products are plant or animal bone biomass originating stable carbon pyrolysis materials with specific quality and safety parameters for explicit soil functional applications..

ABC is an innovative phosphorus natural fertilizer made of food-grade (category 3) animal bones with concentrated > 30 % P_2O_5 content and specific quality for agronomical efficient organic and low input farming applications, also known as Bio-Phosphate.

Thus far, bone char has proven to be efficient in the remediation of heavy metal-contaminated soil and water (link, link) and to be suitable for agronomical applications. In previous studies, bone char (15 % P, 28 % Ca, 0.7 % Mg) provided sufficient P and was also able to immobilize Cd in moderately contaminated soils (link).

Meat and bone meal biochar showed potential for soil amendment, as a liming agent, and for the remediation of Pb in contaminated waters (link). In highly Cd-contaminated soil with sufficient P supply, bone char could increase the yields of lettuce, wheat and potatoes, and at the same time decrease Cd contamination of potato (link). ABC is also suitable as a carrier for microorganisms, mainly P-solubilizing, acting as plant beneficial and biocontrol agents (link, link). However, these studies used lab-scale pyrolysis processes, while an industrial scale pyrolysis system processing all types of category 3 and category 2 animal bones and converting them into ABC has only been recently developed. ABC provides multiple product functionalities in the organic and low input farming sectors, such as organic fertilizer (soil improver, growing medium and/or fertilizing product blends). The substitution of mineral phosphate import by recovered phosphorus is an important goal for European agriculture already in the short term, where ABC is a highly efficient and safe alternative to a large extent in the European industrial dimension. The fully safe ABC is used at low doses (100–600 kg/ha, on average 300 kg/ha) and in a few cases when justified even up to 1000 kg/ha.

The quantity and comparison of mineral content of food-grade ash from cow, goat and pig femur bones for use were investigated through research (link). The bone samples were procured, sun-dried cleaned, incinerated, dry ashed and analysed for their micro and macro mineral contents using the atomic absorption spectrophotometer (AAS) method. The results showed that the femur bones of cows yielded 38.02 % raw ash and 10.60 % dry ash, goats yielded 40.57 % raw ash and 5.86 % dry ash while pigs yielded 35.60 % raw ash and 8.99 % dry ash. Results of macro minerals revealed that calcium content range of 610.63 - 723.16 mg/100 g, sodium 2.15 - 4.07 mg/100 g, magnesium 7.18 - 11.23 mg/100 g, **phosphorus 93.11-280.62 mg/100 g**, while potassium ranged from 2.26 to 3.47 mg/100 g. Micro mineral composition showed that copper ranged from 0.001 - 0.004 mg/kg, iron from 0.022 - 1.93 mg/kg, zinc from 0.016 - 0.144 mg/kg, manganese from 0.007 - 0.108 mg/kg and sulphur from 0.078 - 0.311 mg/kg. All the nonessential heavy metals (toxic minerals) content of the femur bone samples were lower than and recommended safe limit for human consumption and therefore safe. **Cow femur bone had the best mineral composition followed by goat and pig femur bones** (link).

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Description of high temperature reductive thermal process recovery of concentrated phosphorus

Disrupted nutrient recycling is a problem for Europe, while phosphorus and nitrogen are wasted instead of being used for plant nutrition. Mineral phosphate is critical raw material, which contains environmentally hazardous toxic elements such as cadmium and uranium natural contaminations. The global phosphate deposit reserves are insufficient, supply chains are distributed and the higher quality phosphates with lower cadmium content are already depleted, which critical high risk is impacting the European phosphorus supply security. The EU recently strengthened its regulation on cadmium maximum limit. In this context, the European Commission's main concern is to replace the cadmium and uranium content in phosphates as much as is possible with recovered and renewable biobased products, while improving diversification for less cost. Therefore, phosphorus recovery from agricultural and food industrial by-product streams is critically important. Phosphorus recovery from food grade animal bone by-products has been researched since 2002 with objective-driven evolution progress towards specialized pyrolysis processing technology and animal bone char product (ABC - BioPhosphate) developments in economical as well as industrial scale.

Phosphorus (P) mineral fertilisers are found to contain high concentrations of uranium (U) (up to 206 mg U/kg) and other trace elements (TE), such as Cd, Pb, Ni, Cu, Zn, Th, Nb, Sr, V, and rare earth elements.

The apatite is the only mineral containing natural high phosphorus content and has two primarily sourced forms, such as the different types of geologically arranged deposits of mineral phosphate and biobased bones, both with the same high phosphorus content. The standard high P concentration is generally between 30 % - 35 % P_2O_5 in both, mineral and bioapatite.

MINERAL APATITE	Mined mineral phosphate; a non-renewable form, naturally containing high levels of toxic metals cadmium and uranium that are technologically enhanced during the chemical processing
BIO-APATITE	Phosphate calcium phosphate animal bone char: renewable and recovered from food grade animal bones by specific technology and does not contain any toxic metals or chemical additives

Phosphorus is identified with a high supply-risk and high economic importance to which reliable and unhindered access is a significant concern for European agro-industry and food value chains. The new EU Fertilising Products Regulation 1009/2019 defines maximum allowable cadmium limits beyond 2022 and targets massive replacement of imported mineral phosphate fertilisers with biobased recovered alternatives products.

3R-BioPhsohate Ltd. is a specialized organisation to develop, industrial design and implement specific BioPhoshate technology and product applications.

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In Nutri2Cycle, WP2, 30 kg/h capacity commercial market-driven research prototype reactor developed for P fertilizer processing at TRL 4 level, P recovery from animal bones and BIO-NPK-C formulations.

This action is an element of the 2002-2022 BioPhoshate development programme and aims at a wide range of material treatability and alternative formulation research: wider the selection of feed and processing variation opportunities for different types of animal bone feed materials for renewable P fertilizer + alternative BIO-NPK-C product formulations.

However, there is a temporary option to make research compliance under REACH regulation, that is the “Product and Process Orientated Research and Development” PPORD (R&D), consisting of the 3R-BioPhsophate Ltd. activities in the Nutri2Cycle related to:

- development of new substance to recover P from animal bones
- development of specific requirements for the BioPhosphate substance in a defined process or use
- development of new BioPhosphate products including mixtures and articles
- development of new processes to manufacture BioPhosphate
- proving the feasibility of new processes and/or new uses of a substance
- improving efficiency and performance of industrial plant operations
- improving production efficiency from a socio-economic and environmental point of view
- protection of the environment by developing new technology including capturing and ameliorating the waste streams and reducing emissions
- development of recovering, recycling and reusing technologies of valuable materials from by-products, wastes, etc.

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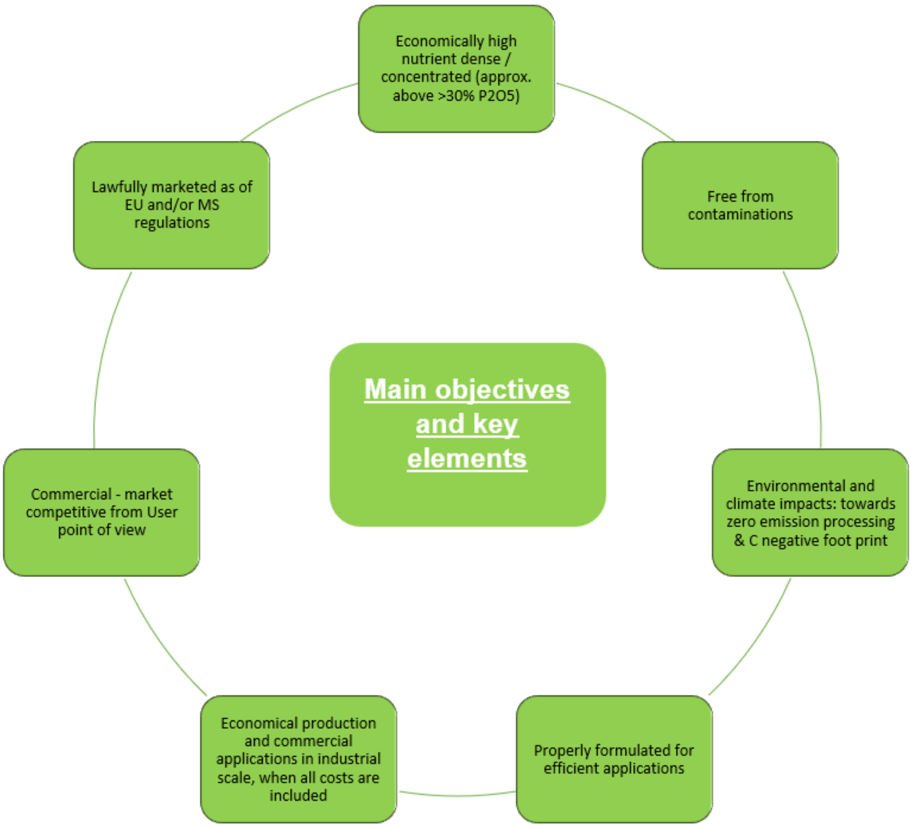

Figure 18. Main objectives and key elements considered that the recovered bio-fertiliser to meet

The bio-origin animal bone is of apatite origin, therefore containing the same high concentrated Phosphorus content as its mineral version. There are no other naturally high Phosphorus concentrated materials than animal bones, but it does not contain potentially toxic elements.

While poultry bones are used for pet food, the cattle bones and part of pig bones are the input materials for the 3R zero-emission technology-based Bio-Phosphate carbon refinery.

However, carbonization of the animal bone requires highly advanced and specifically designed high thermal processing technology at 850°C material core temperature for the production of safe Bio-Phosphate products that meet the new and strict safety and environmental regulations. The Bio-Phosphate phosphorus recovery and carbon refinery is a purposely designed and specific carbonization system with zero-emission performance with an interlinked wide range of BIO-NPK-C formulations, incl. biotechnological formulations as well.

Phosphate import substitution and EU27 replacement value of the Bio-Phosphate technology and product system < 2030 as of conservative calculation and plans = at least > 7 %/year continuous P fertilizer substitution potential in all the EU27 for long term.

The Bio-Phosphate is a new generation Phosphorus recovery technology and production system for organic and low input horticultural applications, that has been expressively developed to meet the new EC Circular Economy Fertilizers Regulation revision (COM (2016) 157) standards and norms and other strict MS regulations as well for the rapidly increasing market demands for safe and economical

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bio-fertilizers. The 3R technology for Bio-Phosphate recovery is a vital part and strategy of the EC Circular Economy Fertilizers Regulation revision.

The Bio-Phosphate is a renewable and high sustainability recovered natural substance that is produced with zero-emission performance and interlinked wide range of BIO-NPK-C formulations, incl. biotechnological formulations as well. All formulations materials used are also renewable and high sustainability recovered natural substance.

Table 65. Preliminary comparison of major characters of 3 pre-selected high and low concentrated recovered Phosphorus product steams

	ABC Bio-Phosphate mg/kg	Struvite mg/kg	Digested manure pellet mg/kg
Farm applications	Organic Low input	Intensive inorganic	Intensive
Average dose kg/ha	300	500	1500
Authority permit	Y	N	Y
Cadmium mg/kg	0,3	0,4	1 (as of high dose main Cd source)
Zn mg/kg	198	139	1.133
Cu mg/kg	2	3	402
Al mg/kg	n/d	n/a	1.073
Fe mg/kg	87	n/a	2.480
Pharmaceuticals	not relevant	high risk	high risk
Illicit drugs	not relevant	high risk	not relevant
Microbial contamination	not relevant	high risk	high risk
PAH 16	0.07	0,12	n/a
PAH 19		n/a	n/a
P2O5 % Phosphorus mg/kg	P2O5: 31,9 % 139.000	P2O5: 23,5 %	P2O5: 5,9 %
Calcium mg/kg	Cao: 41,5 % 297.000	n/a	500
Output production scale tons/year/unit Input in K-tons/y	> 12.500 t/y Input: 21 K-tons/y bone yield = 60 %	9 to 100 t/y	< 9.000 t/y Input: 150 K-tons/y manure yield = 6 %

ABC Animal Bone Char Bio-Phosphate granulate is a high concentrated over 30 % P2O5 phosphate content specific material with macroporous surface characteristics. For agricultural applications, the material is BIO-NPK-C formulated, incl. biotechnologically formulations with Phosphorus mobilization selected fungus strains and adapted by product-specific solid-state fermentation and formulation technology. There are wide ranges of formulations available as well, in any BIO-NPK-C innovative bio-compound fertilizer configurations.

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7.5.2 N2C case scenario

Table 66. Overview of N2C case scenario

Waste input	food grade cattle bones: 20.800 t/year
Energy carriers	autothermal, energy self-sustaining, producing surplus bioenergy 16.000 Mwe/year
Main product	12.500 t/y output BioPhosphate at 35 % P2O5, after BIO-NPK-C/biotech-biochar compound BBF formulation 20.000 t/y
Emissions	ZERO. The 3R is a zero-emission process with C negative product applications.
By-products	none, all material streams converted into useful products
SIMPLE-Baseline	as of organic farming methods
Management	300 kg/ha
Crop rotation	as of organic farming methods
Mechanical management	as of organic farming methods
Chemical management	as of organic farming methods
Fertilisation management	as of organic farming methods
Application of products from innovative technology	phosphate with 35 % P2O5 and a wide range of green compost with biotech formulations
Soil properties	All temperate and Mediterranean soils
Daily precipitation mm/h	Special effect: improving drought tolerance

Waste input for high temperature reductive thermal process recovery of concentrated phosphorus from food grade animal bones is 20.800 t/year of food-grade cattle bones. The main product of this technology is 12.500 t/year output BioPhosphate at 35 % P2O5, after BIO-NPK-C/biotech-biochar compound BBF formulation 20.000 t/year. The 3R is a zero-emission process with C negative product applications, and there are no by-products as all material streams are converted into useful products. Crop rotation, mechanical management, chemical management and fertilisation management are the same as organic farming methods. Application of products from innovative technology implies BioPhosphate with 35 % P2O5 and a wide range of green compost with biotech formulations.

Table 67. Overview of N2C case scenario

New job positions	50/production unit
High skills levels required from workers	yes, the BioPhosphate is an advanced medium scale industrial installation and factory production system
Increase/decrease in traffic, noise and odour	decreased traffic noise and no odour
Substitution of a more impacting input	yes, fully substituting the toxic cadmium/uranium-contaminated (treated mineral and untreated soft) rock phosphate
Training and employee development	yes, a very important element, training as usual at professional industrial installations

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Innovative technology requires 50 new job positions per production unit. High skills levels are required from workers as BioPhosphate is an advanced medium scale industrial installation and factory production system. Training and employee development are very important, and training is carried out as usual at professional industrial installations. This technology has an impact on decreased traffic noise and no odour, and it is fully substituting the toxic cadmium/uranium-contaminated (treated mineral and untreated soft) rock phosphate.

Table 68. Technology cost overview

CAPEX investment cost	3R zero emission processing installation 20.800 t/y throughput capacity and formulation installation: € 15M
CAPEX non-fixed cost	0
repair & maintenance costs	€ 400 k/y
labour costs	€ 1,2 M/y
consumables	€ 250 k/y laboratory cost for product qty evaluations
consumable's fertilizers	N + K + microelements € 350 k/y
administration cost	€ 150 k/y
revenues-subsidies	ROI => 30 %, Pay back =< 4 years. Commercial revenues. (subsidies = 0, market competitive based commercial operations)
revenues-estimated impact on crop yield	Benefits from increased crop yield are counted as a contingency
additional costs/impact on costs (positive or negative)	Marketing and sales organisation € 1M/y

CAPEX investment cost implies 3R zero emission processing installation 20.800 t/y throughput capacity and formulation installation and is € 15 M, and there is no CAPEX non-fixed cost. Repair and maintenance costs amount of € 400 k/y, labour costs € 1,2 M/y, consumables € 250 k/y laboratory cost for product qty evaluations, consumable's fertilizers N + K + microelements € 350 k/y, administration cost € 150 k/y, and marketing and sales organisation amount of € 1 M/y. Benefits from increased crop yield are counted as a contingency.

Table 69. Overview of N2C case scenario

economic costs	EXW wholesale product price € 500/ton (BIO-NPK-C-biotech/biochar formulated compound BBF as of user demand performance)
economic benefits	safe and efficient organic BBF for less cost, JIT supply - no storage cost, high product availability, simple applications.
yield changes	> 5 %
Application rates	Dose average: 200 - 300 kg/ha. The high nutrient density of BBF is critically important that is resulting in low application rates, low user cost and fewer overall impacts.
share of solids and liquids in manure	100 % solid
Nutrient concentrations in digestates, manure (liquid and/or solid matter)	compound BIO-NPK-C organic BBF in any user demanded nutrient concentration
Increased carbon sequestration	Minor C sequestration increase effect expected
Reduced soil erosion	yes, significantly reduced soil erosion

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Runoff and leaching emission reduction rate	yes, significantly reducing runoff/leaching emissions
emission savings, including losses during application	significant emission savings made during processing, logistics and applications
saving rates for fertilizers such as the substitution of mineral fertilizer with manure	full substitution of mineral fertilisers, especially the toxic cadmium/uranium-contaminated mineral/soft rock phosphates
Nutrient specific efficiency increases (Nutrient uptake efficiency)	controlled nutrient release with > 90 % nutrient uptake efficiency in short/medium term
Estimate of current implementation shares of specific innovation in respective countries	significant share > 50 % of the organic BBF market share expected < 2030 in major EU countries

EXW wholesale product price is € 500/ton (BIO-NPK-C-biotech/biochar formulated compound BBF as of user demand performance). Economic benefits are reflected in safe and efficient organic BBF for less cost, JIT supply - no storage cost, high product availability and simple applications, and yield is increased by > 5 %. The average application rate is 200-300 kg/ha, and the high nutrient density of BBF is critically important that is resulting in low application rates, low user cost and fewer overall impacts. This innovative technology significantly reduces soil erosion, runoff/leaching emissions and provides significant emission savings during processing, logistics and applications. It provides full substitution of mineral fertilisers, especially the toxic cadmium/uranium-contaminated mineral/soft rock phosphates and controlled nutrient release with > 90 % nutrient uptake efficiency in the short/medium term. A significant share of > 50 % of the organic BBF market share is expected before 2030 in major EU countries.

Table 70. Overview of N2C case scenario

Economic costs	ROI => 30 % Pay back =< 4 years High CAPEX, low OPEX with high value and market demanded output products
Economic benefits	safe and efficient compound BBF with high nutrient concentration and low dose usage for less cost
"Farming activity" suitability	organic and low input farming systems
"Farm size" suitability	Technology: for medium and large farm-scale operations. Product: applicable at any farm size.
Stakeholder suitability	Technology: medium/large fertiliser producers, large farm systems, rendering operators Product: all users
Applicability at farm level	Technology: for medium/large scale farm operations. Product: applicable at any farm size

This innovative technology has high CAPEX and low OPEX with high value and market demanded output products. It is suitable for organic and low input farming systems, for medium and large-scale operations, medium and large fertiliser producers, large farm systems, rendering operators and it is applicable at any farm size. The main product is the safe and efficient compound BBF with high nutrient concentration and low dose usage for less cost.

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Table 71. Amount and price of different fertilisers on potato per 1 ha

	1 ha potato		
	cattle manure (with 0,4% P)	BBF (with 35% P_2O_5)	mineral fertiliser (superphosphate 40%)
amount	53,3 t	0,46 t	0,4 t
cost	1.799 €	229 €	1.168 €

	1 ha potato		
	cattle manure (with 0,4% P)	BBF (with 35% P_2O_5)	mineral fertiliser (superphosphate 40%)
amount	42,5 t	0,46 t	0,4 t
cost	1.434 €	229 €	1.168 €

As shown in Table 71. the price for fertilization to meet P requirements for 1 ha potato amounts to 229 € for the BBF and 1.168 € for the mineral fertiliser with similar formulation. The cost for fertilization plan of 1 ha potato using cattle manure is 1.434 € but it does not meet requirements of P for 1 ha of potato because it is limited by the amount of N that can be added per hectare by the Nitrates directive (170 kg N/ha).

7.5.3 Financial/Economic analysis – Reference scenario

The reference scenario of potato production implies:

- The use of mineral fertilizers, pesticides and mechanization.

The following tables indicate the gross margin calculations of potato production in standard conditions, the effect of price and GMC on variable cost calculations for Croatia and Belgium in 2019, and finally the recommended fertilization plan for Croatia in 2019.

Table 72. Reference scenario for potato production in Croatia and Belgium (2019)

Reference scenario (Potato)			**Croatia (2019)**	**Belgium (2019)**
Benefits	Yield	kg/ha	30000	46231
	Early var.	€/ha	1.614,79	-
	Late var.	€/ha	2.422,19	-
	Unit price	€/ton	190	250
	Total income	**€/ha**	**5700**	**11.557,75**
Production costs	Seed	€/ha	2.447,75	902
	Mineral fertilizers	€/ha	447	250
	Pesticides	€/ha	605,69	685
	Energy	€/ha	150	150
	Other costs (insurance, redemption, …)	€/ha	-	125
	Total production costs	**€/ha**	**3.500,87**	**2112**
Harvesting costs	Rented mechanization	€/ha	672,83	354
	Own mechanization	€/ha	227,08	125
	Rent land	€/ha	-	750
	Cost of contract work	€/ha	-	600
	Total harvesting costs	**€/ha**	**899,91**	**1825**

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TOTAL COSTS	**€/ha**	**4.400,78**	**3937**
Gross Margin Calculation (GMC)	€/ha	1.299,22	7.620,75

Table 73. Effect of potato price and gross margin calculation on variable cost calculations in Croatia and Belgium

POTATO	**Unit price (€/kg)**		**Gross margin calculation (€/ha)** (no machinery costs)		**Gross margin calculation (€/ha)** (including machinery cost)	
	CROATIA	**BELGIUM**	**CROATIA**	**BELGIUM**	**CROATIA**	**BELGIUM**
Extreme - low	-	-	-	-	-	-
lower price	0,15	0,16	999,12	5.284,96	99,22	3.459,96
average price	0,19	0,25	2.199,12	9.445,75	1.299,22	7.620,75
higher price	0,27	0,34	4.599,12	13.606,54	3.699,22	11.781,54
Extreme - high	-	--	-	-	-	-

In 2019, the cost of 1 kg of potatoes in Croatia ranged from a peak of 0.27 € to a minimum of 0.15 €, with an average price of 0.19 €. However, during the 9th week of 2022, the price dynamics experienced a notable increase. The highest observed price for 1 kg of potatoes surged to €1.10, while the lowest recorded price remained at €0.27. Consequently, the average price for 1 kg of potatoes during the 9th week of 2022 was 0.50 €.

The data of the advisory service of the Ministry of Agriculture and the prices stated in the market information system (TISUP) were used as a source of prices for the gross margin calculation for Croatia.

In 2019, the price range for potatoes in Belgium varied from a minimum of 0.16 € per kilogram to a maximum of 0.34 € per kilogram, with an average price of 0.25 € per kilogram. However, by 2021, the average price of potatoes in Belgium had increased compared to 2019, reaching 0.22 € per kilogram.

The majority of prices used in the analysis refer to official market data from 2019.

Table 74. Recommended fertilization plan for standard potato production in Croatia (2019) (link)

Recommended fertilization Potato (Croatia 2019)					Applied fertilizers / ha				**Fertilizer costs**
Type of fertilizer	Kg N / kg	kg P_2O_5 / kg	kg K_2O / kg	€/kg	**Total kg fertilizers**	**N**	**P_2O_5**	**K_2O**	**€/ha**
CAN	0.27			0,21	**200**	54			**42**
UREA	0.46			0,29	**100**	46			**29**
NPK	0.07	0.2	0.3	0,47	**800**	56	160	240	**376**
Total					**1100**	**156**	**160**	**240**	**447**

7.5.4 Cost-benefit analysis – Innovative scenario

The innovative scenario of potato production refers to:

- development of new substance to recover P from animal bones
- development of specific requirements for the BioPhosphate substance in a defined process or use
- development of new BioPhosphate products including mixtures and articles
- development of new processes to manufacture BioPhosphate
- proving the feasibility of new processes and/or new uses of a substance

- improving efficiency and performance of industrial plant operations
- improving production efficiency from a socio-economic and environmental point of view
- protection of the environment by developing new technology including capturing and ameliorating the waste streams and reducing emissions
- development of recovering, recycling and reusing technologies of valuable materials from by-products, wastes, etc.

The CBA assessment is done by replacing the regular mineral fertilizers by the innovative ABC BioPhosphate.

In conducting the Cost-Benefit Analysis (CBA), the following presumptions are considered:

- the crop yield remains constant and is unaffected by the use of ABC BioPhosphate;
- no extra labour is necessary for the application of ABC BioPhosphate;
- no additional investment in new equipment is needed for applying ABC BioPhosphate;
- all other per-hectare costs (seeds, pesticides, mechanization, insurance, etc.) remain unaltered;
- the harvesting cost (own and rented mechanization, renting land) also remains unaltered

The tables below provided illustrate the gross margin calculations for potato production under innovative technology. Additionally, they showcase the impact of price and Gross Margin Calculation (GMC) on variable cost calculations in both Croatia and Belgium for the year 2019.

Lastly, the recommended fertilization plan for Croatia in 2019. is outlined.

Table 75. Innovative scenario for potato production in Croatia and Belgium (2019)

Innovative scenario (Potato)			**Croatia (2019)**	**Belgium (2019)**
Benefits	Yield	kg/ha	30000	46231
	Early var.	€/ha	1.614,79	-
	Late var.	€/ha	2.422,19	-
	Unit price	€/ton	190	250
	Total income	**€/ha**	**5700**	**11.557,75**
Production costs	Seed	€/ha	2.447,75	902
	ABC Bio-Phosphate	€/ha	150	150
	Pesticides	€/ha	605,69	685
	Energy	€/ha	150	150
	Other costs (insurance, redemption, …)	€/ha	-	125
	Total production costs	**€/ha**	**3.353,34**	**2.012**
Harvesting costs	Rented mechanization	€/ha	672,83	354
	Own mechanization	€/ha	227,08	125
	Rent land	€/ha	-	750
	Cost of contract work	€/ha	-	600
	Total harvesting costs	**€/ha**	**899,91**	**1825**
TOTAL COSTS		**€/ha**	**4.253,25**	**3.841**
Gross Margin Calculation (GMC)		€/ha	1.446,75	7.716,75

Table 76. Effect of potato price and gross margin calculation on variable cost calculations in Croatia and Belgium

POTATO	Unit price (€/kg)		Gross margin calculation (€/ha) (no machinery costs)		Gross margin calculation (€/ha) (including machinery cost)	
	CROATIA	BELGIUM	CROATIA	BELGIUM	CROATIA	BELGIUM
Extreme - low	-	-	-	-	-	-
lower price	0,15	0,16	1.146,56	4.034,96	246,65	3.555,96
average price	0,19	0,25	2.346,56	8.195,75	1.446,75	7.716,75
higher price	0,27	0,34	4.746,56	12.356,54	3.846,65	11.877,54
Extreme - high	-	--	-	-	-	-

Table 77. Recommended fertilization plan if ABC Bio-Phosphate from the innovative case is being used (2019) (link)

Recommended fertilization plan	Kg/ha	N	P_2O_5	K_2O	Fertilizer costs (€/t)
ABC Bio-Phosphate	300		41.7		500

7.5.5 Comparative analysis of innovative scenario and published research

The Bio-Phosphate system is designed to address the drawbacks of non-renewable and imported rock phosphates, known for their high cadmium and uranium content. The goal is to substitute these mineral fertilizers with a more sustainable and environmentally friendly alternative. The system utilizes a natural, safe, and renewable source of high-phosphorus concentration, primarily derived from the apatite mineral. This mineral is found in two major natural forms: mineral phosphates and bio-origin animal bones. The innovative fertilizer produced by the Bio-Phosphate system offers a cost-effective solution with high nutrient concentration, aiming to reduce environmental contamination and greenhouse gas emissions associated with traditional fertilizers.

In one of the founded publications on this topic, functional properties and conducted an agronomic evaluation of biofertilizers produced from sewage sludge ash and animal bones, enriched with the bacteria Bacillus megaterium in comparison to conventional fertilizers specifically in the context of spring wheat production were performed. The results showed that biofertilizers derived from ash and bones demonstrated matching crop-enhancing efficiency to commercial fertilizers, with the added benefit that the bone-derived biofertilizer led to a greater weight of wheat crop residues (roots in particular). It was also noted that the used biofertilizers did not change the soil pH (link).

One of the experiments demonstrated the conversion of fish bones, typically overlooked in valorization processes, into valuable agricultural materials (calcium phosphate) through a simple and scalable thermal process (in an oxidizing environment, not by pyrolysis) suitable for community implementation even in the least developed countries. Like biochar, the economic viability of the suggested method for manufacturing fertilizers and biostimulants from fish bones relies primarily on the expenses associated with biomass collection and labour that is in turn related to the GDP per capita. In both industrial and artisanal settings, fish bones, typically already separated from meat for human consumption, incur no additional collection costs compared to other biomass sources in the context of this study. The estimated cost of biochar production presented in the paper was approximately 144 USD per ton, demonstrating economic feasibility. This is supported by a profitable margin, considering that market prices for standard phosphate fertilizers in 2020 ranged between 500 € and 800 € per ton (link).

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

Within the research, it was explored the potential use of different *Bacillus sp.* bacterial strains for the microbial solubilization of phosphorus-containing waste materials such as fishbones, bones and ash derived from incineration of sewage sludge. Results showed that fish bones exhibited the most substantial bioavailable phosphorus, constituting 20.5 % of the total content, with 99.1 % being bioavailable. The optimal solubilization efficiency (over 70 %) was achieved by combining fishbone and sewage sludge ash (1:1) using a consortium of three bacterial strains. The resulting liquid biofertilizer, containing 0.54 % P2O5 and elevated micronutrients such as iron (0.16 %), demonstrated biological effectiveness in plant studies, with seeds soaked in the biofertilizer showing significant root stimulation (up to 33 %) and a chlorophyll content increase of over 20 % (link).

7.5.6 Conclusions

Standard production of potatoes includes mineral fertilization, while production under innovative conditions includes the use of bio-based fertilizers, specifically in this case - ABC Bio-Phosphate.

As a result of distinct production conditions, both standard and innovative scenarios involve different variable costs. In the financial analysis of the innovative scenario, a reduction in production costs occurs due to the smaller quantities needed for fertilization.

The total variable costs in standard potato production amount to 3.500,88 €/ha in Croatia and 2.112 €/ha in Belgium, while in innovative production they amount to 3.353,34 €/ha in Croatia and 2.012 €/ha in Belgium.

Utilizing an innovative scenario has proven to be beneficial, resulting in reduced production costs for potatoes and enhanced overall profitability. Calculations are based on the EXW wholesale product price derived from the 5.5.1 Technology background section, which stands at 500 € per ton for the final product ABC Bio-Phosphate and based on the recommended fertilization plan for ABC Bio-Phosphate, indicating a required product amount is 300 kg/ha. So, the price of fertilization in the innovative scenario is 150 €/ha. The Gross Margin Coefficient (GMC) margin in the innovative scenario for Croatia is calculated at 1.446,75 € and in the reference scenario that is 1.299,22 €.

In the reference scenario, using mineral fertilizers yields a GMC margin of 7.620,75 € in Flanders, the GMC in the innovative scenario amounts to 7.716,75 €. These figures underscore the comparative profitability and cost-effectiveness of the innovative scenario across different regions.

Table 78. Overview of data used as reference to CBA study

Data	**Reference CBA Study**	**Type of data**	**Source of data (Croatia)**	**Source of data (Flanders)**
Preliminary comparison of major characters of ABC Bio-Phosphate mg/kg	Table 65	Sector publication	Publication by Biofarm Agri Research Station Hungary and Universita Degli Studi di Torino, Italy, Publication by University of Agriculture, Umudike, Nigeria	
Preliminary comparison of major characters of struvite mg/kg	Table 65	Sector publication	Publication by Biofarm Agri Research Station Hungary and Universita Degli Studi di Torino, Italy, Publication by University of	

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			Agriculture, Umudike, Nigeria	
Preliminary comparison of major characters of digested manure pellet mg/kg	Table 65	Sector publication	Publication by Biofarm Agri Research Station Hungary and Universita Degli Studi di Torino, Italy, Publication by University of Agriculture, Umudike, Nigeria	
Overview of N2C case scenario – main product: BioPhosphate from waste input food grade cattle bones	Table 66	Project produced data	D2.6	D2.6
Overview of N2C case scenario for new job positions	Table 67	Project produced data	D2.6	D2.6
Technology cost overview	Table 68	Project produced data	D3.3	D3.3
Overview of N2C case scenario – economic benefits for BIO-NPK-C-biotech/biochar	Table 69	Project produced data	D3.3	D3.3
Overview of N2C case scenario – farm suitability	Table 70	Project produced data	D3.3	D3.3
Amount and price of different fertilisers on potato per 1 ha	Table 71	Project produced data	D3.3	D3.3
Baseline info - benefits of potato (yield, early var., late var., unit price)	Table 72	Sector publication	The data of the advisory service of the Ministry of Agriculture	Sector information (stakeholder interaction)
Baseline info – production cost (seed, mineral fertilizers, pesticides, energy, other costs)	Table 72	Sector publication	The data of the advisory service of the Ministry of Agriculture	Sector information (stakeholder interaction)
Baseline info - Total production costs	Table 72	Project produced data	D3.3	D3.3
Baseline info – harvesting cost (rented mechanization, own mechanization, rent land, cost of contract work)	Table 72	Sector publication	The data of the advisory service of the Ministry of Agriculture	Sector information (stakeholder interaction)
Total harvesting costs	Table 72	Project produced data	D3.3	D3.3
Total costs (production cost + harvesting cost)	Table 72	Project produced data	D3.3	D3.3
Baseline info - Gross Margin Calculation (GMC)	Table 72	Project produced data	D3.3	D3.3
Baseline info - Unit price (€/kg) of potato	Table 73	Sector publication	TISUP	
Baseline info - Gross margin calculation (€/ha) (no machinery costs)	Table 73	Project produced data	D3.3	D3.3
Baseline info - Gross margin calculation (€/ha) (including machinery costs)	Table 73	Project produced data	D3.3	D3.3
Composition CAN	Table 74	Sector publication	The data of the advisory service of the Ministry of Agriculture	
Composition UREA	Table 74	Sector publication	The data of the advisory service of the Ministry of Agriculture	

Composition NPK	Table 74	Sector publication	The data of the advisory service of the Ministry of Agriculture	
Fertilizers costs (CAN, UREA, NPK)	Table 74	Sector publication	The data of the advisory service of the Ministry of Agriculture	
Innovative scenario for potato – benefits (yield, early, late, unit price)	Table 75	Sector publication	The data of the advisory service of the Ministry of Agriculture	
Innovative scenario for potato – production cost	Table 75	Sector publication	The data of the advisory service of the Ministry of Agriculture	
Innovative scenario – total production cost	Table 75	Project produced data	D3.3	D3.3
Innovative scenario for potato – harvesting cost	Table 75	Sector publication	The data of the advisory service of the Ministry of Agriculture	
Innovative scenario – total harvesting cost	Table 75	Project produced data	D3.3	D3.3
Innovative scenario - Gross margin calculation	Table 75	Project produced data	D3.3	D3.3
Innovative scenario – unit price (€/kg) of potato	Table 76	Sector publication	TISUP	
Innovative scenario - Gross margin calculation (€/ha) (no machinery costs)	Table 76	Project produced data	D3.3	D3.3
Innovative scenario- Gross margin calculation (€/ha) (including machinery costs)	Table 76	Project produced data	D3.3	D3.3
Recommended fertilization plan (digestate; AS; liquid fraction)	Table 77	Sector publication	The data of the advisory service of the Ministry of Agriculture	

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

7.6 LL49 & LL65 Phosphorous recovery from pig manure via struvite crystallisation and design of struvite based tailor-made fertilisers

The crystallization of phosphorus (and nitrogen) in the form of magnesium ammonium phosphate hexahydrate also known as MAP or struvite is one of the possible techniques used to eliminate and/or recover nutrients. Depending on the source material used, the quality of the struvite may differ. The most distinct variation can be observed between the struvites produced from sludge liquor (SL) (rather pure) and the one produced directly from the sludge (LQ) (containing more impurities). Production of struvite from digestate is also possible. The obtained product can be applied as a base in ecological fertilizers of high quality. The digestate produced in the AD process has been recovered as a slow-release fertiliser through the crystallization process as struvite. Ammonium and phosphate can be removed from the digestate by precipitation of struvite (MAP) resulting struvite is a good fertiliser because N, P and magnesium (Mg) are valuable nutrients for plants.

This technology was researched in both #LL49 and #LL65 and is therefore assessed in 1 overall cost benefit analysis. The table below gives an overview of the TRL level and the agro typology according to both those researches.

Table 79. TRL level and application in the different agro typologies

		LL49	LL65
TRL Level		6	6
Agro Typology	Pig production		
	Poultry production		
	Cattle Farming		
	Open field cultivation of cereals or maize	X	X
	Open air cultivation of vegetables	X	X
	Orchards	X	X
	Agro-energy systems	X	X
	Animal by-product processing	X	X

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

7.6.1 Background information

Struvite (MAP)

Struvite or MAP is a white crystalline substance formed by the combination of magnesium, phosphate, and ammonium in equal molar amounts. Struvite is a good slow-release fertiliser and provides essential nutrients such as magnesium, nitrogen and phosphorus for agriculture and horticulture. Another factor that supports the use of struvite as a fertiliser is its low concentration in heavy metals compared to the phosphate rock usually used in the manufacture of synthetic fertilisers. Due to its slow release, the delivery of nutrients is carried out gradually and the plant consumes them according to its requirements, thus avoiding the leaching of these nutrients and their arrival to the water masses, as can occur when synthetic fertilisers are applied. It is therefore required less frequency of application and there is no burning of the plant, even at high rates of application.

Struvite cannot currently be marketed as a fertiliser product in many EU countries, as it does not have end-of-waste status. Exceptions to this situation are the Netherlands, Belgium, and Germany.

The main products of innovative technology are shown in Table 80. including the phosphorus content of both products. This product can replace all or part of the mineral fertilizers currently applied.

Table 80. Main products of innovative technology

INPUT	
Type	**%**
Digestate from pig manure	99,56%
Magnesium Chloride	0,17%
Sodium Hydroxide	0,27%

OUTPUT	
Type	**%**
Struvite	0,06%
Liquid fertilizer	99,94%

The composition of the struvite based on the pig manure is N-P-K (%) 4.7-11.2-0.6 (and 10 % Mg).

7.6.2 Financial/Economic analysis – Reference scenario

The reference scenario for the assessment of the cost benefit analysis for the application of struvite is similar to the scenario used for the assessment of the N-fertilizers (see earlier in this document). For Croatia the same reference scenario and fertilization recommendation can be used.

Table 81. Recommended fertilization (only mineral fertilizers) for the region of Croatia

Recommended fertilization Maize with only mineral fertilizers (Croatia 2019)					**Applied fertilizers kg / ha**				**Fertilizer costs**
Type of fertilizer	Kg N / kg	kg P2O5 / kg	kg K2O / kg	€/kg	**Total kg fertilizers**	**N**	**P2O5**	**K2O**	**€/ha**
CAN	0,27			0,21	**180**	48,6			**37,8**
UREA	0,46			0,3	**100**	46			**30**
NPK	0,07	0,2	0,3	0,5	**450**	31,5	90	135	**225**
NPK	0,15	0,15	0,15	0,32	**150**	22,5	22,5	22,5	**48**
Total					**880**	**148,6**	**112,5**	**157,5**	**340,8**

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For the region of Flanders, a different reference scenario needs to be chosen, as the reference scenario for the N-fertilizers (in the sandy soil) did not use any mineral P-fertilizers (only manure was applied for bringing on the P-load to the arable land). Therefore, for this assessment a clay soil will be used as functional unit.

Table 82. Recommended fertilization of maize for the region of Flanders

		Recommended fertilization Maize (Flanders 2019)				
		Applied fertilizers kg / ha				**Fertilizer costs**
Type of fertilizer	€/kg	**Total kg fertilizers**	**Neff**	**P2O5**	**K2O**	**€/ha**
Manure (or manure derived products)	0	35000	97	50	165	**0**
Triple super phosphate	0,3	87		40		**26,09**
CAN	0,21	104	28			**21,8**
KCl	0,19	25			15	**4,625**
Total		**35216**	**125**	**90**	**180**	**52,49**

7.6.3 N2C case scenario

Similar to the assessment of the N-fertilizers, the struvite is implemented as a P-fertilizer in the fertilization for growing maize. The same boundary conditions are set, i.e. no change in crop yields, no need for addition investment, etc. For a manure extensive region this would result in the following fertilisation strategy per ha of maize for both scenarios (i.e. the reference and the use of struvite).

Table 83. Possible fertilization strategy when using struvite in manure extensive regions (maize production)

Manure extensive region					
	Fertilizers				
		kg/ha	kg N/ha	kg P2O5/ha	kg K2O /ha
Reference	CAN	180	48,6		
	UREA	100	46		
	NPK	450	31,5	90	135
	NPK	150	22,5	22,5	22,5
	TOTAL	**880**	**149**	**113**	**158**
Struvite	**Struvite**	1004	47,2	112,5	6,03
	CAN	376	101,4		
	KCl	252			151,47
	Total	**1632**	**149**	**113**	**158**

Where for a manure intensive region it results in the overview below.

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Table 84. Possible fertilization strategy when using struvite in a manure intensive region (maize production)

Manure intensive region - Clay soil					
	Fertilizers				
		kg/ha	kg N/ha	kg P2O5/ha	kg K2O /ha
Reference	Triple super phosphate	87		40	
	Manure	35000	97	50	165
	CAN	104	28		
	KCl	25			15
	TOTAL	**35216**	**125**	**90**	**180**
Scen 1	**Struvite**	357	17	40	2,14
	Manure	35000	97	50	165
	CAN	42	11		
	KCl	21			12,86
	Total	**35420**	**125**	**90**	**180**

7.6.4 Cost Benefit analysis – Innovative scenario

When taking into account the fertilization strategies for the different scenarios (as indicated in table 83 and 84) the total costs per hectare (€/ha) can be calculated for the reference scenario. This cost is based on the current prices of the applied fertilizers in combination with the transport cost (= cost for application of the fertilizer on the arable land).

As there is no market price set yet for the novel biobased fertilizer struvite, the maximum price that the fertilizer can have is deducted by assuming that the total cost per hectare for fertilization (€/ha) cannot exceed the total cost of the reference scenario.

Table 85. Economic assessment use of struvite for a manure extensive region (maize production)

Manure extensive region								
	Fertilizers				Transport 2 €/ton	Total Costs	Benefit compared to reference	Max cost BBF/kg
		€/kg	kg/ha	**€/ha**	€/ha	€/ha	€/ha	€/kg
Reference	CAN	0,21	180	**37,8**				
	UREA	0,3	100	**30**				
	NPK	0,5	450	**225**				
	NPK	0,32	150	**48**				
	TOTAL		**880**	**340,8**	**2**	343		
Struvite	**Struvite**		1004	**0**				
	CAN	0,3	376	**112,7**				
	KCl	0,2	252	**50,49**				
	Total		**1632**	**163**	**3**	166	176	0,175

Table 86. Economic assessment use of struvite for a manure intensive region (maize production)

Manure intensive region - Clay soil								
	Fertilizers				Transport 4 €/ton	Total Costs	Benefit compared to reference	Max cost BBF/kg
		€/kg	kg/ha	**€/ha**	€/ha	€/ha	€/ha	€/kg
Reference	Triple super phosphate	0,3	87	**26,1**				
	Manure	0,00	35000	**0,0**				
	CAN	0,21	104	**21,8**				
	KCl	0,19	25	**4,6**				
	TOTAL		**35216**	**52,6**	**141**	193		
Scen 1	**Struvite**		357	**0**				
	Manure	0	35000	**0**				
	CAN	0,21	42	**8,7**				
	KCl	0,2	21	**4,3**				
	Total		**35420**	**13**	**142**	155	39	0,108

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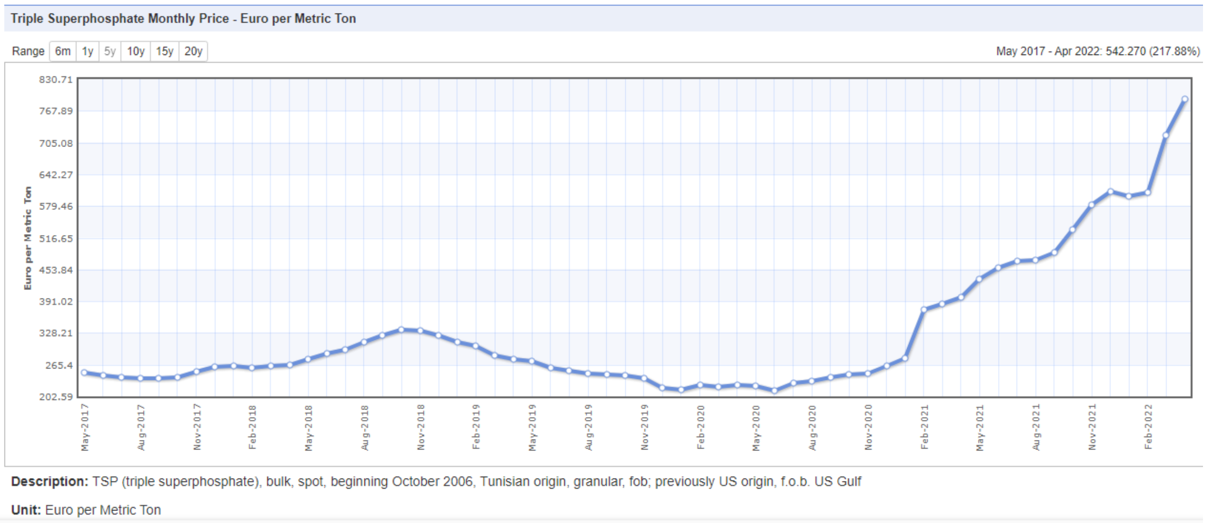
Within the frame of the market prices of 2019 of mineral fertilizers, this results in a maximum value for struvite of 0.175 €/kg in Croatia and 0.108 €/kg in Flanders. If a farmer can purchase struvite (in the same quality as assumed here) for a price that is below this maximum price, the overall costs for fertilization will be lower and there will be an economic benefit.

Impact of price fluctuations

The maximum values calculated were based on the values of the market prices in 2019. Lately the prices for the mineral fertilizers have shown significant fluctuations (steep increase). Also the cost of P-fertilizers (Triple super phosphate).



Triple Superphosphate Monthly Price - Euro per Metric Ton

Description: TSP (triple superphosphate), bulk, spot, beginning October 2006, Tunisian origin, granular, fob; previously US origin, f.o.b. US Gulf

Unit: Euro per Metric Ton

Figure 19. Price variation of Triple Super Phosphate (source : www.indexmundi.com)

As within this economic assessment the maximal price for the recovered nutrient (struvite) was back-calculated from the current prices of mineral fertilizers, this will have a direct impact on the outcome of the research.

The tables below show the impact of the variations of the prices for mineral fertilizers, where the "average" situation represents the situation of 2019. It can be concluded that for the situation in which the prices of the mineral fertilizers would reach (and stay) at the "extreme high" market prices, the market price of the struvite may increase up to 0.529 €/kg in Croatia and 0.330 €/kg in Flanders.

Table 87. Impact of variations in the price of mineral fertilizers (manure extensive region)

Manure Extensive region		**EXTREME LOW**	**LOW**	**AVERAGE (2019)**	**HIGH (2022)**	**EXTREME HIGH**
		-25%	**-10%**	**Ref**	**2019 +200 %**	**+100% of 2022**
		€/kg	**€/kg**	**€/kg**	**€/kg**	**€/kg**
Reference	CAN	0,1575	0,189	0,21	0,63	1,26
	UREA	0,225	0,27	0,3	0,9	1,8
	NPK	0,375	0,45	0,5	1,5	3
	NPK	0,24	0,288	0,32	0,96	1,92
	Cost / ha	**257**	**308**	**343**	**1024**	**2047**
Struvite	CAN	0,225	0,27	0,3	0,9	1,8
	KCl	0,15	0,18	0,2	0,6	1,2
	Struvite	0,131	0,158	0,175	0,529	1,060

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Table 88. Impact of variations in the price of mineral fertilizers (Flanders)

Manure intensive region		EXTREME LOW	LOW	AVERAGE (2019)	HIGH (2022)	EXTREME HIGH
		-25%	-10%	Ref	2019 +200 %	+100% of 2022
		€/kg	€/kg	€/kg	€/kg	€/kg
Reference	Triple super phosphate	0,225	0,27	0,3	0,9	1,8
	Manure	0	0	0	0	0
	CAN	0,1575	0,189	0,21	0,63	1,26
	KCl	0,13875	0,1665	0,185	0,555	1,11
	Cost / ha	**180**	**188**	**193**	**299**	**456**
Struvite	Manure	0	0	0	0	0
	CAN	0,1575	0,189	0,21	0,63	1,26
	KCl	0,15	0,18	0,2	0,6	1,2
	Struvite	0,081	0,097	0,108	0,330	0,662

7.6.5 Comparative analysis of innovative scenario and published research

The crystallization of nutrients, specifically phosphorus and nitrogen, in the form of magnesium ammonium phosphate hexahydrate, commonly known as MAP or struvite, represents a viable technique for nutrient elimination and recovery. Struvite, a white crystalline substance comprising magnesium, phosphate, and ammonium in equal molar proportions, serves as a beneficial slow-release fertilizer, providing essential nutrients like magnesium, nitrogen, and phosphorus for agricultural and horticultural purposes. Despite its potential, struvite lacks end-of-waste status in many EU countries, except for the Netherlands, Belgium, and Germany.

In the context of fertilizing maize crops in this case, struvite is employed as a phosphorus fertilizer. However, its marketability as a fertilizer product is hindered by the absence of established market prices in several regions. As of 2019, considering prevailing market prices for mineral fertilizers, the potential value of struvite is capped at 0.175 €/kg in Croatia and 0.108 €/kg in Flanders. Anticipated increases in the market price could push struvite values to a maximum of 0.529 €/kg in Croatia and 0.330 €/kg in Flanders. These figures underscore the evolving landscape of struvite's economic viability as a novel, biobased fertilizer.

Struvite precipitation is a highly effective physicochemical treatment method widely employed for removing and recovering excess nitrogen and phosphorus from wastewater, generating a valuable byproduct. Despite its prevalence in literature, there is a notable lack of emphasis on the economic aspects of the process, with most attention directed toward the impact of chemical combinations and operating conditions. Addressing this gap, one of the founded study conducts a comprehensive feasibility analysis of struvite recovery for a full-scale fertilizer production facility with a 500 m^3/day capacity (link).

Through quantitative assessment, experimental conditions and chemical combinations were performed to meet ammonium nitrogen discharge standards, considering a multitude of economic and operational parameters. The study explores the influence of changes in struvite sale prices on profit margins under optimal conditions, calculating investment and operating costs based on the latest market values. Findings indicate that with a struvite sale price increase to 560 €/ton, the facility could achieve a net profit of €445.62/day, potentially recovering its initial investment in approximately six years. This underscores the economic viability of struvite precipitation, suggesting its increasing adoption as an effective and environmentally friendly process in the future (link).

Marketability of struvite faces challenges due to the absence of established market prices in various regions. This lack of pricing standards can hinder its widespread adoption as a commercial fertilizer product.

7.6.6 Conclusions

The tables above give an overview of what the farmers could pay for the recovered struvite without impact on the economic balance of their production. This means that if they can buy the bio-based fertilizers for a price below this indicated maximum values, they will have a financial benefit for their production compared to the reference scenario. For the current market prices (i.e. situation 2019) the farmer should not pay more than 0.175 €/kg in a manure extensive region or 0.108 €/kg in a manure intensive region. If the market price for the mineral fertilizers increase significantly, i.e. comparable to the market value in beginning of 2022, the farmer can pay up to 0.529 €/kg in the manure extensive region.

The research showed as well that the price for struvite can be up to 62 % higher in manure extensive regions.

Table 89. Overview of data used as reference to CBA study

Data	**Reference CBA Study**	**Type of data**	**Source of data (Croatia)**	**Source of data (Flanders)**
Main products of innovative technology	Table 80	Project produced data	D2.6	
Composition CAN	Table 81	Sector publication	The data of the advisory service of the Ministry of Agriculture	
Composition UREA	Table 81	Sector publication	The data of the advisory service of the Ministry of Agriculture	
Composition NPK	Table 81	Sector publication	The data of the advisory service of the Ministry of Agriculture	
Composition NPK	Table 81	Sector publication	The data of the advisory service of the Ministry of Agriculture	
Fertilizers costs (CAN, UREA, NPK)	Table 81	Sector publication	The data of the advisory service of the Ministry of Agriculture	
Composition of manure	Table 82	Sector publication	-	Web research
Composition of CAN	Table 82	Sector publication	-	Web research
Composition of triple super phosphate	Table 82	Sector publication	-	Web research
Composition of KCl	Table 82	Sector publication	-	Web research
Fertilizers costs (manure, triple super phosphate, CAN, KCl)	Table 82	Sector publication	The data of the advisory service of the Ministry of Agriculture	
Possible fertilization strategy when using struvite in manure extensive regions (maize production)	Table 83	Project produced data	D3.3	D3.3
Possible fertilization strategy when using struvite in a manure intensive region (maize production)	Table 84	Project produced data	D3.3	D3.3
Economic assessment use of struvite for a manure extensive/intensive region, maize production	Tables 85 & 86	Project produced data	D3.3	D3.3
Impact of variations in the price of mineral fertilizers (manure extensive region)	Table 87	Project produced data	D3.3	D3.3

Impact of variations in the price of mineral fertilizers (Flanders)	Table 88	Project produced data	D3.3	D3.3

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

8. Research Line 5: Novel animal feeds produced from agro-residues

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

The aim of this solution is the recuperation of nutrients from liquid agro-residues by growing protein-rich floating wetland plants.

Figure 20. LL41 – Scheme of technology

Plants take up nutrients like phosphate, ammonium and nitrate to grow. These nutrients are pollutants in liquid agro residues. However, these are also essential nutrients for plant growth and can still be applied to some floating wetland plants. To tackle the question on contaminations, water content, and salinity, three different set-ups are currently available, i.e., a growing rack, a cube container cascade and a pond of 140 m². Since duckweed can treat manure and convert it into valuable proteins, it is a nice example of closing nutrient loops.

Some parameters about the growth and possible applications of duckweed are available. This fast-growing plant has the potential to replace non-sustainable protein sources in the feedstock.

This innovation can be implemented in pig production, cattle farming and animal by-product processing. As it is to be implemented on the effluent of a manure treatment plant, only the region of Flanders will be assessed in this CBA, given that there are no manure treatment plants in Croatia.

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

8.1.1. Background information

In those regions where there is more manure available than can be disposed on arable land solutions have been sought for handling the excesses in available nutrients (nitrogen and phosphorous). One of the solutions for handling this excess in nutrients is the destruction of the nutrients in biological manure treatment systems. Figure 3 gives an overview of the manure treatment facilities that are operational in Flanders.

The most important step of such a manure treatment installation is the aerobic step (activated sludge system) in which the ammonia (NH_4^+) present in the manure (or liquid fraction of the manure) is transformed to the gaseous N_2 that is omitted to the environment. The phosphorous present in the manure (or liquid fraction of the manure) will be captured in the activated sludge by adding $FeCl_3$. The output of this type of manure treatment facility is the so called "bio-logical effluent".

Without any further treatment this effluent does not meet the discharge limits for discharging to surface water. That makes that there are 2 options to do: (i) dispose the effluent as manure on arable land or (ii) further treat the effluent to meet discharge limits. The disadvantage of the first option is that the period in which it is allowed to dispose manure on land is limited, what would result in the necessity of a large storage volume to store all the effluent. On top of that the disposal of all the biological effluent is also labour intensive and a significant disposal cost (estimated 4 €/ton – sector data 2021). The further treatment of the effluent can be done in multiple ways, e.g. the installation of membrane treatment (UF-RO) or the treatment in a "constructed wetland".

Constructed wetlands with reedbeds are aquatic plant-based systems designed specifically for the removal of nitrogen from dilute waste water as it passes through the vegetative filter. They are relatively inexpensive to construct but may require a large area of land to provide an adequate level of treatment.

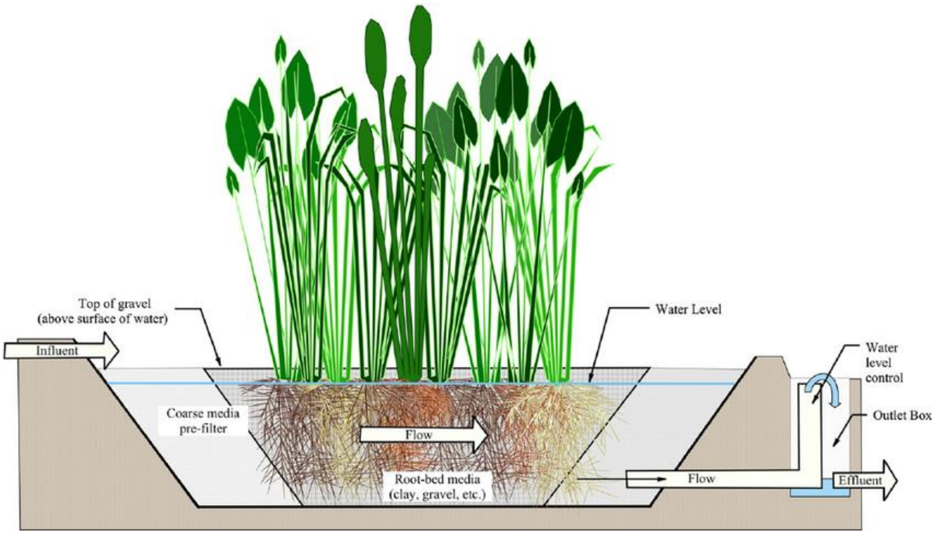

Figure 21. Water flow path through a subsurface flow constructed wetland (link)

The wetlands are a constructed, semi-natural area of land typically comprising beds of different specialised plants such as reeds and gravel-filled channels (link). The effluent from the well-known constructed wetlands can be used for crop and pastureland irrigation. According to the BAT-study a nitrogen removal efficiency of 20 - 60 % can be obtained in the regular wetlands. This efficiency can be increased to 90 % with floating aquatic macrophytes.

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The technology researched in the Nutri-2-Cycle project does not involve the regular constructed wetland with reeds but uses duck-weed as plants for the uptake of the nutrients (= floating wetlands). This duck-week can in turn be used as animal feed.

8.1.2. N2C-case scenario

The implementation of the duck weed instead of the classic wetland system is actually only a change in the type of green biomass that is grown while treating the biological effluent.

The input to the floating wetland consists of 4812 ton/year of the effluent of the biological treatment. The composition of this effluent is indicated in table 91. In addition to that also rain water will go into the system, with an estimated maximum of 840 m^3/ha.year.

The output from the system is multiple:

- Duck weed that can be directly fed as substitute for soybean meal to the pigs
- Dischargeable water
- Sediment

Table 90. Overview of the output of the floating wetlands (1 ha)

OUTPUT				
		Duck weed	Dischargeable water	Sediment
	ton DM/year	10,72	4521	
	ton DM/day	0,061		
	m^3/year		4521	1120
	m^3/day		25,8	
Component	unit	Duck weed	Dischargeable water	
Dry weight (DW)	g/100g	5,6		
Crude protein	% DW	29,1		
Crude fibre	% DW	12,5		
NDF	% DW	40,1		
ADF	% DW	18,5		
Lignin	% DW	5,7		
Crude fat	% DW	6,1		
Ash	% DW	15,9		
Energy value	MJ/kg DW	18,2		
BOD	mg/L		25	
N_{total}	mg/L		15	
P_{total}	mg/L		2	
Cl	mg/L		1000	
TSS	mg/L		35	

The water can only be discharged when the discharge limits for discharging on surface water are met. The main limiting parameters are BOD (25 mg/L), COD (125 mg/L), chloride (1000 mg/L), TSS (35 mg/L), Ntot (15 mg/L) and P_{tot} (2 mg/L) (source: Vlarem II – Bijlage 5.3.2). The research on the technology (cfr. Deliverable D2.6) shows that it can be expected to discharge around 4521 m^3/year what corresponds to a discharge tax of around 630 €/year.

The sediment builds up in the wetland, and only has to be removed every 10 years. This sediment can then be disposed on land (as manure). Nevertheless, to make a correct assessment a yearly cost is accounted for this disposal of sediment.

8.1.3. Financial/Economic analysis – Reference scenario

The starting point for making the comparison is the quality of the biological effluent.

Table 91. Composition of the biological effluent as reference for the CBA assessment

Component	unit	Concentration
Dry solids	g/L	12.5
Organic matter	g/L	3.6
N_{total}	g N/L	0,4
P_{total}	g P_2O_5 /L	0,2
K	g K_2O /L	3,7
Mg	g MgO/L	0,1

In order to make a good comparison, the use of the "floating wetlands" will be compared to 2 reference scenarios:

(i) disposal of the biological effluent on arable land
(ii) Treatment of the biological effluent in a standard constructed wetland

Disposal on arable land

When disposing the biological effluent to arable land it has to comply with the manure legislation. This legislation limits the amount of effluent that can be disposed per ha arable land, implies a significant administrative framework that has to be implemented etc. But most importantly is the fact that the disposal on land in only possible for a limited time, and a storage with a capacity of at least 6 months has to be available at the site. For this case study, where a total amount of 4812 m^3 of biological effluent would be treated in a time frame of almost half a year (175 days) this would correspond to a storage volume of 4812 m^3. When taking into account that the investment in storage capacity (lagoon type) corresponds to 20 €/m^3 (*data source: input from the sector on data in 2021)*, this would correspond to an investment of around 96.000 €.

Other aspects that have to be taken into account when disposing on arable land:

- There is no need for electricity, fuel or labour;
- Disposal cost are estimated at 4 €/ton (*data source: input from the sector*);
- Cost for land purchase (for the construction of the storage) is not taken into account;
- Soybean Meal will have to be purchased in an equivalent amount to the amount of duckweed that would be produced in a floating wetland. The table below gives a comparison of the energy value of both components (link).

Table 92. Comparison of the energy value of duck weed and soybean meal (link)

		Duck weed	Soybean meal
Energy value	MJ/kg	18,2	14,2548
	kcal / kg	4346	3394

The 10.72 ton duck weed that would be produced corresponds to an energetic value of 0.2 MJ/year.

Given the energy value of soybean meal to be a bit below the energy value of duck weed, this would correspond to 13.7 ton of soybean meal to be purchased per year. The market price of soybean was considered 470 €/ton (link).

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Standard constructed wetland

When assessing the standard constructed wetland the main focus of the treatment is the production of the dischargeable effluent. In a classic constructed wetland there is the production of biomass (reed). This biomass can be composted and used as a fertilizer. Often manure treatment plants have a composting facility for the thick fraction of the incoming manure and therefore no additional investments for supporting this composting were taken into account.

Literature research learns that the costs for the operation of a classic constructed wetland varies between 3.5 and 4 €/ton (link). Those costs consist of:

- Costs for electricity
- Labour costs (estimated 0.5hr per day)
- Discharging the final effluent (= taxes)
- Disposal of the biomass (composting)
- Maintenance (estimated 10 % of the investment)

The same study also states that 1 ha of classic wetland can treat about 10.000 m^3/year. According to the BREF study "Best Available Techniques Reference document for the intensive rearing of poultry or pigs" (pg. 721) the investment cost of a classing wetland system corresponds to around 32.000 €/ha (data from 2011). Taking into account a general price increase of 40 % over the past 10 years, this would correspond to an investment cost of around 45.000 €/ha.

8.1.4. Cost benefit analysis - Innovative scenario

The table below summarizes the different scenarios as discussed above with the main financial aspects. The evaluation is done both per ha of floating wetland (treating the total amount of 4812 m^3) and per m^3 of biological effluent treated.

The assessment shows that the operational costs (€/year) are the highest in the scenario where all the effluent is disposed on land. This is mainly due to the cost of transport of the effluent (estimated at 4€/ton). The situation with the floating wetland results in the lowest operational costs (€/year), notwithstanding the highest maintenance costs. The main benefit in the scenario with the duckweed lies in the avoided costs of purchase of feed (around 6.400 €/year).

On the other hand, the investment is in this evaluation the most determining factor – where in the scenario with the disposal on land the bigger investment goes to additional storage volume, the additional costs for the duckweed production is even more significant, even almost the double of the reference scenario. The installation with the regular constructed wetland shows to be by far the cheaper investment, and therefor also the best scenario from an economic point of view.

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Table 93. CBA assessment for the different scenarios on the treatment of biological effluent

			Amount of biological effluent treated (m3/year)			Per unit (m3) of biological treatment		
			4812			1		
			Disposal on land	Regular constructed wetland	Floating wetland (duck weed)	Disposal on land	Regular constructed wetland	Floating wetland (duck weed)
Operational costs	Electricity	kWh_e /year		21000	2316,5			
		€/kWh_e		0,24				
		€/year		**5040**	**556**	**0**	**1,05**	**0,12**
	Fuel	kWh/year		0	2240			
		€/kWh		0,053				
		€/year		**0**	**118,72**	**0**	**0**	**0,02**
	Labour (40.000 €/year)	hr/day	0	0,5	0,5			
		€/year	**0**	**2500**	**2500**	**0,00**	**0,52**	**0,52**
	Feed equivalent Floating wetland : duck weed Other scenarios : soybean meal	ton DM/year	13,68	13,68	10,72			
		MJ/ton	0,0143		0,0182			
		MJ/year	0,20	0,20	0,20			
		€/ton	470	470				
		€/year	**6432**	**6432**		**1,34**	**1,34**	**0,00**
	Disposal of manure or liquid fraction	ton/year	4812	4521	4521			
		€/ton	4	0,14	0,14			
		€/year	**19248**	**630**	**630**	**4,00**	**0,13**	**0,13**
	Disposal of biomass	ton/year		40				
		€/ton		5				
		€/year		**200**		**0,00**	**0,04**	**0,00**
	Disposal of sediments	ton/year		1120	1120			
		€/ton		5				
		€/year		**5601**	**5601**	**0,00**	**1,16**	**1,16**
	Maintenance	**€/year**		**2250**	**8500**	**0,00**	**0,47**	**1,77**
	TOTAL OPERATIONAL COSTS	**€/year**	**25680**	**22653**	**17906**	**5,3**	**4,7**	**3,7**
Impact of investment (comparison to scen 1)		**€/year**		-3026,59	-7773,48		-0,63	-1,62
INVESTMENT	Storage	m3	4812					
		€/m3	20					
	Surface wetland	ha		0,5	1			
		€/ha		45000	176000			
	Total investment	**€**	**96240**	**22500**	**176000**	**20,0**	**4,7**	**36,6**
	impact of investment (comparison to scen 1)	**€**		**-73740**	**79760**		**-15,32**	**16,58**
	Depreciation period	years	10					
	Annualised investment cost	**€/year**	**9624**	**2250**	**17600**	**2**	**0,47**	**3,66**
	impact of investment (comparison to scen 1)	**€/year**		**-7374**	**7976**		**-1,53**	**1,66**
	Overall balance	**€/year**		**-10401**	**203**		**-2,16**	**0,04**
	Payback Period (compared to scen 1)	**years**		**-24,36**	**10,26**		**-24,36**	**10,26**

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8.1.5. Comparative analysis of innovative scenario and published research

The Nutri-2-Cycle project has delved into an innovative approach to wastewater treatment that diverges from conventional constructed wetlands featuring reeds. Instead, this technology embraces the use of duckweed as a dynamic plant medium for nutrient uptake, giving rise to what is commonly known as floating wetlands. Notably distinct from traditional methods, these floating wetlands present a unique dual-purpose functionality, as the harvested duckweed holds the potential to serve as valuable animal feed.

Based on the conclusion from other research, constructed wetlands offer an economical and efficient wastewater treatment solution, boasting remarkably low operational and maintenance costs, typically ranging from 1 % to 2 % of the initial plant expenditure. This cost-effectiveness positions constructed wetlands as a compelling alternative for treating diverse wastewater streams, including agricultural wastewater, industrial dairy wastewater, industrial tannery wastewater and industrial textile wastewater (link).

In contrast to alternative technologies such as the Activated Sludge Process (ASP), Moving Bed Biofilm Reactor (MBBR), Trickling Filter, Up-flow Anaerobic Baffled Reactor (UASB), and Sequential Batch Reactor (SBR), constructed wetlands necessitate more space. However, this trade-off is mitigated by their significantly lower operational and maintenance costs, amounting to only 1 %–2 % of the capital cost, making them a financially prudent choice (link).

Beyond financial considerations, constructed wetlands present a visually appealing and odor-free solution to wastewater treatment, distinguishing them from other methods. Their aesthetic integration into the environment enhances their appeal, creating a harmonious and sustainable approach to effectively address water pollution challenges. In summary, constructed wetlands emerge as a cost-effective, technically viable, and environmentally pleasing strategy for wastewater treatment, demonstrating a commitment to sustainability through minimal operational impact and optimal cost efficiency (link).

8.1.6. Conclusions

The assessment shows that the installation of a wetland can significantly lower the operational costs, mainly due to the diminishment of the cost for disposal of the liquid fraction. For the floating wetlands is the investment almost double the investment for the reference (= storage + disposal on land) what makes that the benefit of lower operational costs is almost erased resulting in a similar yearly balance with only 0.04 €/m^3_{treated} difference. The additional investment that would be required for implementing a floating wetland would be recovered only after a period of around 10 years (= payback period).

For the classical constructed wetlands, the investment is a lot lower though, what makes that this scenario stands out as the most favourable one: both the operational costs are significantly lower than the reference, but also the investment is only around 25 % of the investment for the storage capacity. The negative overall balance and payback period indicates that this scenario is a lot more economically sustainable then scenario 1.

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Table 94. Overview of data used as reference to CBA study

Data	Reference CBA Study	Type of data	Source of data
Overview of the output of the floating wetlands (1 ha)	Table 90	Project produced data	D3.3
Composition of the biological effluent as reference for the CBA assessment	Table 91	Project produced data	D3.3
Comparison of the energy value of duck weed and soybean meal	Table 92	Sector publication, data sector info	https://www.intechopen.com/chapters/19972
Operational costs of treatment of biological effluent (disposal on land)	Table 93	Sector publication, data sector info	Literature published by Siedlce University, Natural Faculty, Poland , Input from the sector on data in 2021,
Operational costs of treatment of biological effluent (regular constructed wetland)	Table 93	Sector publication	Literature published by Siedlce University, Natural Faculty, Poland
Operational costs of treatment of biological effluent (floating wetland (duck weed))	Table 93	Sector publication	Literature published by Siedlce University, Natural Faculty, Poland
Investment costs of treatment of biological effluent (disposal on land)	Table 93	Data sector info	Input from the sector
Investment costs of treatment of biological effluent (regular constructed wetland)	Table 93	Sector publication	BREF study “Best Available Techniques Reference document for the intensive rearing of poultry or pigs” (pg. 721)
Investment costs of treatment of biological effluent (floating wetland (duck weed))	Table 93	Sector publication	BREF study “Best Available Techniques Reference document for the intensive rearing of poultry or pigs” (pg. 721)
Payback period of treatment of biological effluent (regular constructed wetland)	Table 93	Project produced data	D3.3
Payback period of treatment of biological effluent (floating wetland (duck weed))	Table 93	Project produced data	D3.3

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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.

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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.