Cover Delivery Report

Title of the Deliverable:	D.3.7 Report on application of the Business Development Package to ten outreach locations
WP Title and Number:	WP3 Systemic innovations at EU Outreach Locations
Date of completion:	29 November 2021
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Name of the responsible WP Leader:	Marieke Verbeke
Date of approval by the Coordinator	30 November 2021

The research was undertaken as part of the project called 'SYSTEMIC: Systemic large scale eco-innovation to advance circular economy and mineral recovery from organic waste in Europe.

https://systemicproject.eu

This report has been submitted to the EC for approval and as such it is still to be considered as draft.

This project has received funding from the European Union's H2020 research and innovation programme under the grant agreement No: 730400. SYSTEMIC started 1 June 2017 and will continue for 4,5 years.

2021

D 3.7 Report on application of the Business Development Package to ten outreach locations

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Bruges, 30 November 2021

Document type: Public Report

Deliverable D3.7

Horizon 2020

History of changes

Date	Changes

Content

List of abbreviations

AD : Anaerobic digestion

AP: Associated Plants

AS : Ammonium sulphate solution

BDP: Business Development Package

CAPEX: Capital Expenditures

CIP: Cleaning in place

CHP: Combined Heat and Power (gas engine)

DAF: Dissolved air flotation

DM : Dry matter

DP: Demonstration Plants

FM : Fresh matter

GZV : Groot Zevert Vergisting

IE: Ion exchange

JRC : Joint Research Centre (European Commission)

KPI: Key performance indicator

Ktonne: kilo tonnes

kWh el: kiloWatthours electrical energy

kWh th: kiloWatthours thermal energy (heat)

LBG: Liquefied bio-methane gas (or Bio-LNG: Bio-liquefied natural gas)

LF : Liquid fraction

MWel: MegaWatt electric (electric capacity)

NRR : Nutrient recovery and reuse

NVZ: Nitrate Vulnerable Zone

OL: Outreach Location(s)

OPEX: Operational Expenditures

TRL: technology readiness level

RO : Reverse osmosis

SF : Solid fraction

WENR : Wageningen Environmental Research

WP: Work Package

WWT: wastewater treatment

WWTP : wastewater treatment plant

2 List of definitions

Term	Definition
Digestate	Solid material remaining after the anaerobic digestion of a biodegradable feedstock.
LF of digestate	Liquid fraction (LF) after separation of digestate by a decanter centrifuge or screw press or belt press.
SF of digestate	Solid fraction (SF) after separation of digestate by a decanter centrifuge or screw press or belt press.
Dried SF of digestate	Solid fraction of digestate after a thermal drying process
Evaporator concentrate	Remaining liquid fraction of digestate, after evaporation of water and volatile components.
RO concentrate	Concentrate remaining after removal of water from a liquid stream (liquid fraction of digestate or evaporator concentrate) by reverse osmosis (RO).
Condensed ammonia water	Condensate after evaporation of liquid fraction of digestate with a high content of ammonium, and treated by reverse osmosis to reduce the water content (high concentration of nitrogen (N).
Ammonium sulphate solution	Solution of ammonium sulphate obtained after ammonia stripping followed by recovery of gaseous ammonia in sulphuric acid (Acqua & Sole) or with gypsum (FiberPlus at BENAS)
Permeate water	Permeate after reverse osmosis which needs further purification by means of ionic exchange (IO) prior to discharge to surface water
Purified water	Water recovered from digestate by means of reverse osmosis and ionic exchange, purified to be used as process water or to be discharged to surface water.
Low-phosphorus organic soil improver	Solid fraction of the digestate after flushing with water and sulphuric acid to remove most of the phosphorus (P).
Precipitated phosphate salts	Precipitated phosphate salts, obtained by precipitation of phosphate (PO_4) with calcium or magnesium and which is a recovered as a sludge or in solid form, as calciumphosphate or magnesiumammoniumphosphate (struvite).
Low-nitrogen organic fibres	Solid fraction obtained by a screw press from digestate after nitrogen (N) stripping-scrubbing in the Fiberplus system and used for production of fibre.
Calcium carbonate sludge	Precipitate of calcium and carbonate produced as a side product of the FiberPlus N stripping unit at BENAS by the reaction of striped air containing ammonia and carbon dioxide with gypsum ($CaSO_4$) leading to the formation of ammonium sulphate and calcium carbonate precipitate.

3 List of demonstration plants

Demonstration plant	Abbreviation
BENAS	BNS
Am-Power	AmP
Groot Zevert Vergisting	GZV
Acqua & Sole	A&S
Waterleau NewEnergy	WNE

Preface

This deliverable 3.7 was carried out and published as a part of the European demonstration project SYSTEMIC funded by the H2020 programme (project number 730400). The project SYSTEMIC focuses at five large scale biogas demonstration plants where innovative nutrient recovery processing techniques were implemented and monitored.

This report includes a description of the SYSTEMIC Outreach Locations and their journey of exploring nutrient recovery and reuse (NRR) from digestate during the project. The Outreach Locations are regarded as the first followers of the Demo Plants and are supposed set an example for other biogas plants in Europe on how to actively learn from each other and from a growing network of other stakeholders related to the biogas sector.

Based on the outcomes of the SYSTEMIC project, WP3 has designed a Business Development Package (BDP), which provides a step-wise business development roadmap, including different levels of details, to make sure biogas plants can start or continue exploring and evaluating technologies for NRR for their business case.

The Outreach Locations were actively involved in this process throughout the project and together with the SYSTEMIC consortium the content of the BDP has been applied to their specific biogas plant.

We would like to acknowledge the plant owners and staff of all Outreach Locations, Demo Plants and Associated Plants for their involvement in this deliverable. Also Teija Paavola from Atria (Finland) for being closely involved in the writing process and technical evaluations of the NUTRICAS Tool simulations and Karin Tonderski from Linköping University (Biogas Research Centre) for information about the Swedish regulations for digestate and fertiliser use in the Götene area in Sweden.

The authors

Summary

One of the tasks within the SYSTEMIC project was to develop a Business Development Package (BDP, Deliverable 3.6 "Business Development Package and SYSTEMIC calculation tools as guidance materials for implementation of NRR technologies at large scale anaerobic digesters") which is publicly available and was officially launched on 30th of November 2021.

The BDP is a tool for existing and emerging biogas plants, providing a step-by-step approach to help them with exploring and decision making for implementation of the innovative business cases with nutrient recovery from digestate (https://systemicproject.eu/bdp/).

The Outreach Locations (OL) were actively involved in this process throughout the SYSTEMIC project and together with the consortium the content of the BDP has been applied to their specific biogas plant.

Specifically, next to a description of each Outreach Locations' business environment and drivers for nutrient recovery, the NUTRICAS Tool was used to make simulations for mass balances and cost estimations for technologies for nutrient recovery and resue (NRR) that might have potential in their business case.

Using information from the BDP, the consortium evaluated with the OL for each suggestion or simulation the how realistic the simulated outcomes were, and if the simulations would be interesting to investigate further in detail on their potential for implementation in practice.

Many of the OL were interested in the NRR cascades that could reduce the volume of the digestate by producing dischargeable water, i.e. membrane filtration + reverse osmosis, evaporation + reverse osmosis or drying. Simulations showed that to achieve a performant membrane filtration system on digestate an advanced pre-treatment and finetuning would be necessary, including steps like optimal pre-separation (including additives like flocculants, a DAF unit, paper filters or dilution of the RO input. The associated operational costs associated to maintenance during calamities or disturbances of the efficiency of this sensitive system were not included in the NUTRICAS simulations. In practice pilot tests should be performed to better estimate the actual performance of these systems within the plant's internal boundary conditions on the longer term.

The impact of removing N from digestate and concentrating it in a separate product with low organic matter was also simulated, mainly for OL which were located in NVZ. The advantage of the specific end products of these technologies would be that the N stripped digestate could then be applied on a smaller surface of land before meeting the N application limits. The revenues for the produced ammonium scrubber salts could also include a market opportunity as a cheaper and greener alternative for synthetic N fertilisers, since these are liquid N products containing low amounts of organic matter. However, the acceptance of farmers for these products is in many regions still low, let alone that a positive price would be paid for these products. Implementation of the RENURE criteria (Huygens et al. 2020) and designing a dedicated market strategy could improve this current market circumstances for scrubber salts.

NUTRICAS simulations for phosphorus recovery currently only prove to be possibly cost-effective in the case of wastewater treatment sludge digestion and struvite recovery. The RePeat cascade seems promising in the tested cases because of its relatively low CAPEX, yet the OPEX is high because of the chemical consumption and high volumes of residual sludge streams and costs for product storage. Also, revenues from the produced Calcium phosphate sludge and P-low soil improver have also not been positive yet because the composition and form still needs to be optimized to fit the desired (niche) markets. However, implementation of the RePeat technology in another region, i.e. business environment, combined with further optimisation of the end products and market development in that region might have a totally different outcome and prove to be profitable after all.

Even though validated on the operational technology cascades of the Demo plants and Key Outreach Location Nurmon Bioenergia, the NUTRICAS is only able to provide a rough mass balance and cost estimation because it is using standard recovery rates, default amounts of chemicals, a limited amount of available data on CAPEX and a generalized value for OPEX.

In practice, a detailed cost estimation is depending on many additional factors that could not be taken into account in the NUTRICAS Tool: a tailor-made technology cascade for each specific biogas plant's case, the different types of digestate and changes in its composition, specific foreseen maintenance regime, calamities and unforeseen circumstances, different technology suppliers with more detailed offers, experience of the staff, gate fees and fluctuating marketing revenues and disposal costs of all produced end products.

However, by creating this report it has been confirmed by the OL that the NUTRICAS Tool is a very valuable tool to explore the different NRR technologies. More detailed data on the specific technologies can be found on the BDP and additional contacts with the SYSTEMIC consortium, and SYSTEMIC EU biogas plant network can further facilitate the set-up of a detailed business plan and eventual decision-making on the implementation of the NRR technology (cascade).

1 Introduction

To transfer the knowledge and experiences regarding nutrient recovery and reuse (NRR) from the SYSTEMIC biogas Demo Plants to the next level of followers, 10 Outreach Locations were selected during the project. These 10 biogas plants all over Europe had interest in the practical application of the studied NRR technologies in SYSTEMIC. During the project, Living Lab meetings were organised (physical and online), to exchange experiences, problems, bottlenecks and solutions and enhance knowledge transfer between practitioners, academics and industry, meanwhile showing real-life business cases with NRR as examples during site visits and presentations. The Living Lab concept developed and executed within the SYSTEMIC project proved to be successful, with 10 Outreach Locations (OL) and 20+ Associated Plants being involved in the network of European biogas plants.

Additionally, it was the intention of SYSTEMIC to keep this useful network of biogas plants alive after the project and even expand it. Therefore, one of the tasks within the SYSTEMIC project was to develop a Business Development Package (BDP,(Verbeke, Hermann, Brienza, et al. 2021a)) which is publicly available and was officially launched on 30th of November 2021.

Business Development Package

The BDP has become a tool for existing and emerging biogas plants, providing a step-by-step approach to help them with exploring and decision making for implementation of the innovative business cases with nutrient recovery from digestate (https://systemicproject.eu/bdp).

The BDP was designed to provide a comprehensive overview of the SYSTEMIC project results that are most relevant for biogas plants to be used in practice. It is structured in a way that the most straightforward and comprehensible information is found first, and that the information gets more detailed for the more advanced or experienced biogas plant owners, who would really like to read all the details.

The main target group for the BDP are European anaerobic digestion biogas plants, however policy makers, technology developers, research institutes, consultants, mineral fertiliser industry, etc. could also make use of the BDP's tools and output.

NUTRICAS Tool

An important part of the BDP is the NUTRICAS calculation and simulation tool for cost benefit analysis and technology selection (https://systemicproject.eu/bdp/technologies-and-mass-balances/). It is an exploratory tool to estimate the composition of end products, costs (CAPEX, OPEX, chemical costs) for technology combinations for nutrient recovery from digestate. It has been user tested on its user-friendliness by EU biogas plants to be used without the requirement of a manual.

The SYSTEMIC Outreach Locations have been actively involved in the development of the BDP and NUTRICAS Tool and were the first to test it out. Together with the SYSTEMIC consortium, both tools were used to explore which (configuration of) technologies for NRR could be applicable and beneficial for their specific business case.

Economic KPI Tool

Another important part of the BDP is the KPI Tool. Economic Key Performance Indicators (KPIs) are quantifiable and can help to understand how an organisation is performing. They can be associated with targets which the organisations should set and pursue and aim at quantifying their achievement.

In the context of the SYSTEMIC project, specific KPIs were developed for biogas plants. They translate the technical values into commercial indicators such as cost per unit of biogas, feedstock or digestate. The KPI tool will be able to calculate in an easy way 5 main economic Key Performance Indicators for user's biogas plant business case. The quantified KPIs will be calculated by the tool and can be compared to the KPIs of other EU biogas plants who have also used the KPI Tool. The tool can do a KPI evaluation of an existing biogas plant's business performance, but can also be used to perform simulations on how the KPIs would change when implementing certain NRR technologies, cutting specific costs or getting other revenues from end products, etc.

The Outreach Locations have been a part of the user testing group to optimise the KPI tool's user-friendliness. The application of the KPI tool to the OL was not possible for this report because it was still under development at the time of application and because it calculates KPIs of existing business cases and this would be opposed to the confidentiality of each OL's financial figures.
Because of the variability in the simulation's cost estimations of the NUTRICAS simulations, calculating economic KPIs for simulations of NRR technologies on these existing business cases would render too wide variability in the results to draw any reliable conclusions.

2 Methodology

From the start of the project, 11 Outreach Locations have been selected to be intensively involved in the process of knowledge exchange and transfer within the SYTEMIC project (Figure 2-1, A). This included: Atria – Nurmon BioEnergia (FI), Bojana (HR), Biogas Bree (BE), Ferme du Faascht (BE), GMB – BIR BV (NL), Waternet (NL), Waterleau NewEnergy (BE), Greengas AD (IR), Emeraude BioEnergie (FR), Somenergia – Biogas Makassar (ES) and Biogastur (ES).

During the project, Biogastur had to withdraw themselves as Outreach Location and Waterleau NewEnergy was upgraded to a Demonstration Plant, while RIKA BioTech -Fridays (UK) became an Outreach Location instead (Figure 2-1, B).

Because the involvement in SYSTEMIC and the application of the BDP requires close collaboration between the consortium and each Outreach Location, after 4 years some OL were not able to muster the time to dedicate to this process. Greengas AD, Biogas Makassar and Emeraude BioEnergie and RIKA BioTech were not able to provide the time or data to perform a dedicated evaluation with the BDP.

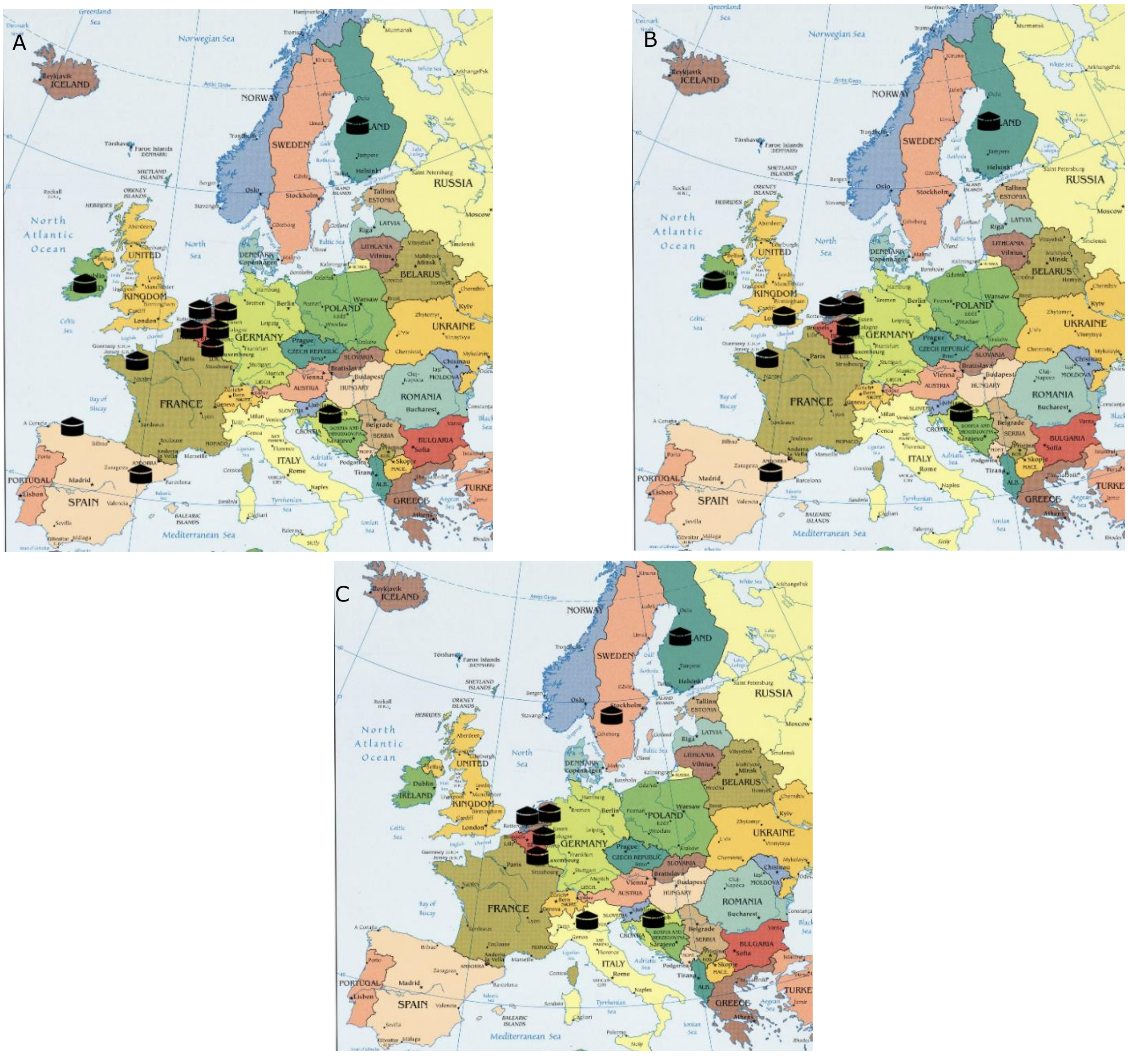

Figure 2-1 (A) Eleven SYSTEMIC Outreach Locations selected in November 2017. (B) Ten SYSTEMIC Outreach Locations after withdrawal of Biogastur (December 2018) and replacement of Waterleau NewEnergy by RIKA. (C) Eight SYSTEMIC Outreach Locations described in this report for application of the Business Development Package.

Instead, 2 Associated Plants (Gasum Götene -SE and Biomeco AD – IT) were added as Outreach Location to make up for the decreasing amount of Outreach Locations (Figure 2-1,C).

Available information on Greengas AD, Biogas Makassar and Emeraude BioEnergie and RIKA BioTech is provided in ANNEX II.

In the report **all OL are divided in one of two categories**:

1) Existing biogas plants
   These biogas plants are existing biogas plants, initially without advanced NRR technologies installed for digestate treatment. Over the years or even during the period of the SYSTEMIC project they have been gradually evaluating and implementing NRR technologies and/or would like to investigate which NRR technologies would be able to improve their current business case even more.
2) New biogas plants to be built, designed with NRR
   These are biogas plants, that are specifically designed to include a digestate treatment cascade with recovery of nutrients and/or water. These plants would not be able to exist without the NRR cascade because the whole business plan has been built on marketing of specific NRR end products instead of raw digestate. However, in most cases there is still room for changes to their NRR digestate treatment cascade to further improve their business plan.

Description of the company and business environment

First a short description is given about the company owning or operating the biogas plant, after which their local business environment is described. This includes the availability of certain feedstocks, competition of other fertilising products, main crops cultivated in the region and regional legislation for nutrient soil application related to nitrogen (Figure 2-2) and phosphorus in the soil (Figure 2-3) and livestock density (Figure 2-4).

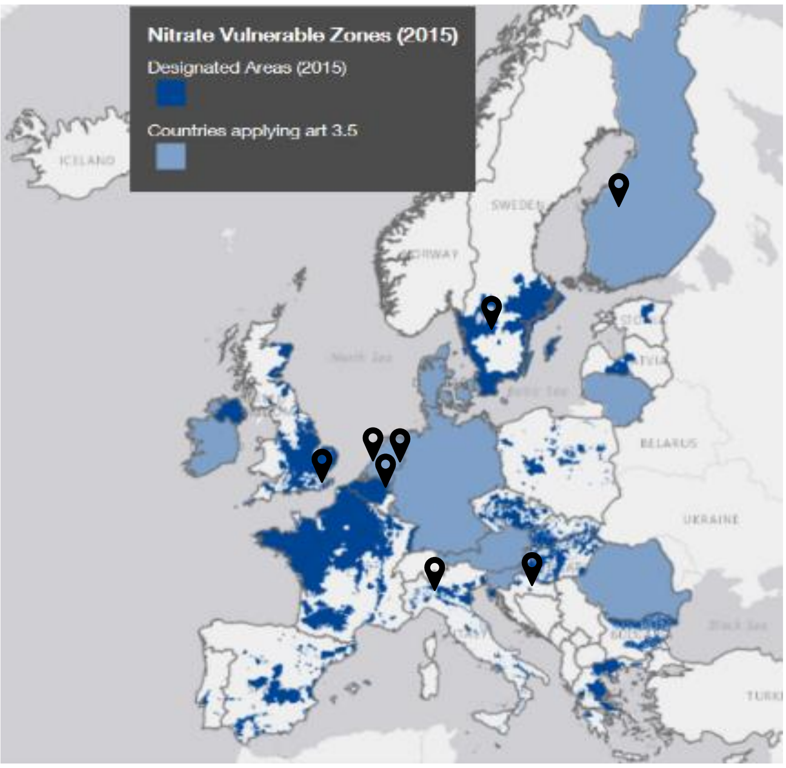

Figure 2-2 Nitrate Vulnerable Zones in Europe. Pins represent SYSTEMIC Outreach Locations described in the report. Source: https://water.jrc.ec.europa.eu/portal/apps/webappviewer/index.html?id=d651ecd9f5774080aad738958906b51b

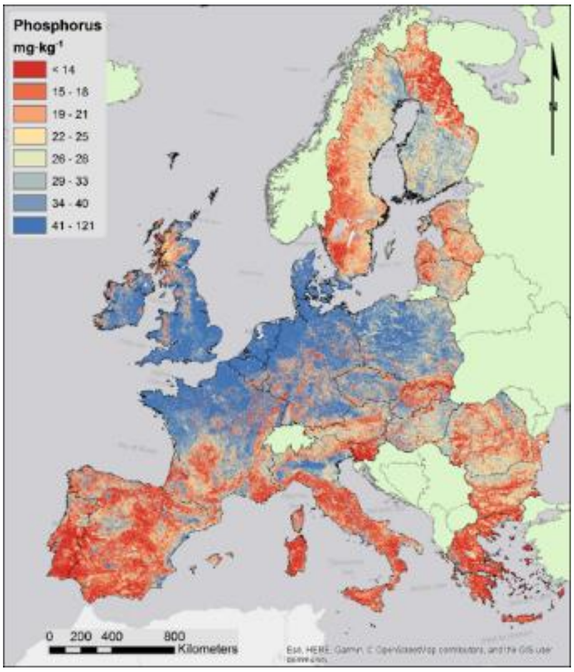

Figure 2-3 Phosphorus in the topsoil in Europe (LUCAS 2009/2012 topsoil data)

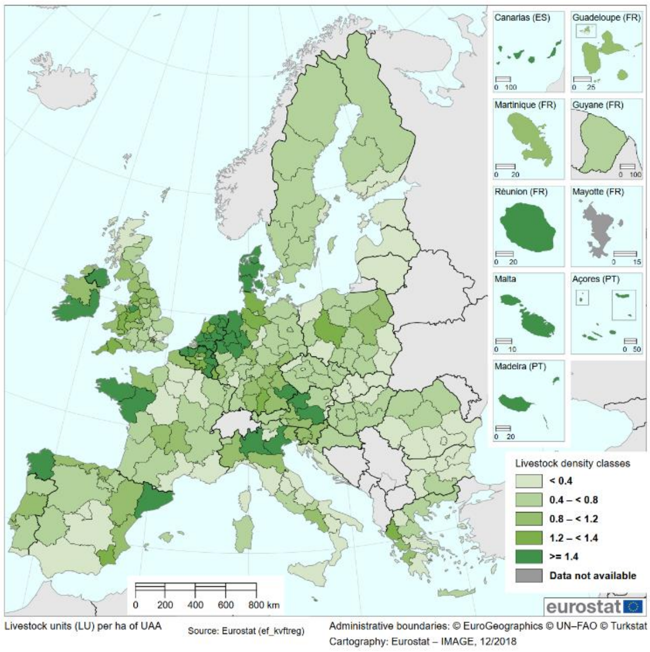

Figure 2-4 Livestock density in units per hectare of utilised agricultural area: cropland + grassland (UAA) (Eurostat: Livestock density by NUTS 2 regions, EU-28, 2016)

Business case evolution during SYSTEMIC

The next part of each chapter describes the plant and its learning and development process with regard to NRR during the SYSTEMIC project (June 2017 – November 2021).

Suggestions made by SYSTEMIC and the BDP

In this part, the NUTRICAS Tool was used to simulate specific NRR cascades for each OL. The OL could suggest which cascades they would like to have simulated:

- **Acidification + evaporation + reverse osmosis**
  according to the NUTRICAS calculation model: "Evaporation after acidification to pH 6.5, 80°C"

This scenario is implemented at Demo plant Am-Power and the calculation model was validated with estimated data of key Outreach Location Nurmon Bioenergia, which will use the same technology cascade when the biogas plant is built.

- **Evaporation + N stripping-scrubbing + reverse osmosis**
  according to the NUTRICAS calculation models: "Evaporation at pH 7.8, 80°C" and "CO_2 stripping to pH 8.8, 65°C, 80% of NH_4-N stripped"

This specific cascade is not as such available in the NUTRICAS Tool but it includes a combination of 3 cascades that are available in the Tool (i.e. Evaporation , N stripping-scrubbing and reverse osmosis). The simulation was performed by combining the results of the simulations in the Excel version of the NUTRICAS Tool. The calculation model for evaporation and RO was validated with estimated data of key Outreach Location Nurmon Bioenergia (FI) and data from Demo Plant Waterleau NewEnergy (BE). The calculation model for N stripping-scrubbing is based on different N stripping-scrubbing units, creating an estimation for a "default" N stripping-scrubbing unit working without carrier material (to increase the air/liquid surface inside the stripper).

- **N stripping-scrubbing**
  according to the NUTRICAS calculation model : "CO_2 stripping to pH 8.8, 65°C, 80% of NH_4-N stripped"

In this model sulphuric acid is used as scrubbing agent for ammonia, producing an ammonium sulphate solution as scrubber salt. The calculation model is based on different N stripping-scrubbing units working on digestate from different technology suppliers, creating an estimation for a "default" N stripping-scrubbing unit working without packing material.

- **N stripping-scrubbing + acidification + evaporation + reverse osmosis**
  according to the NUTRICAS calculation models: "CO_2 stripping to pH 8.8, 65°C, 80% of NH_4-N stripped" and "Evaporation after acidification to pH 6.5, 80°C"

This specific cascade is not as such available in the NUTRICAS Tool but it includes a combination of 2 cascades that are available in the tool (N stripping-scrubbing and acidified evaporation + reverse osmosis). The simulation was performed by combining the results of both simulations. . The calculation model is based on different N stripping-scrubbing units working on digestate from different technology suppliers, creating an estimation for a "default" N stripping-scrubbing unit working without packing material. The calculation model for evaporation and RO was validated with estimated data of key Outreach Location Nurmon Bioenergia.

- **N stripping-scrubbing with Fiberplus system**
  according to the NUTRICAS calculation model: "CO_2 stripping to pH 7.8, 80°C, 80% of NH_4-N stripped.

This calculation model was validated with data of the existing NRR technologies implemented at Demo Plant BENAS. The FiberPlus system was developed by GNS (BENAS Gruppe). However, the NUTRICAS calculation excludes fiber extraction and paper making from the N stripped digestate fibers.

- **Microfiltration + reverse osmosis + ion exchange**

This NUTRICAS calculation model was validated with data of the existing GENIUS NRR cascade implemented at Demo Plant Groot Zevert Vergisting. GENIUS was developed by Nijhuis Industries.

- **RePeat on solid fraction**

The NUTRICAS calculation model was validated with data of the existing RePeat cascade implemented at Demo Plant Groot Zevert Vergisting. RePeat was developed by Wageningen Environmental Research.

- **RePeat acididfiction step**

This specific cascade includes only a part of the RePeat cascade and is not as such available in the NUTRICAS Tool. The Excel version of the tool was used to perform this simulation.

The simulation was based on the calculation model validated with data of the existing RePeat cascade implemented at Demo Plant Groot Zevert Vergisting, combined with data from (Regelink, Ehlert, and Römkens 2017).

More details about the calculation models in the NUTRICAS Tool and underlying figures can be found in "NUTRICAS Tool Description"[1].

Using information from the BDP, the consortium evaluated with the OL for each simulation the how realistic the simulated outcomes were, and if the simulations would be interesting to investigate further in detail on their potential for implementation in practice.

In most cases, the marketability of the simulated end products would still need to be explored further but for example benchmarking manure derived digestate products against the developed RENURE-criteria (Table 2-1) might already reveal possible increased market prices for these products (see section 4).

[1] https://systemicproject.eu/bdp/technologies-and-mass-balances under the "NUTRICAS tool description".

Impact of SYSTEMIC

The involvement of the Outreach Locations during the SYSTEMIC project and how the SYSTEMIC project has had an impact on their knowledge and network with regard to NRR, will be described for each OL.

Future plans

Taking into account the developments that each OL has accomplished in the past 4.5 years at their biogas plant, the involvement of SYSTEMIC, suggestions done by the NUTRICAS Tool etc., each OL plans for the future development of their biogas plant will be described.

Table 2-1 RENURE criteria proposed in the SAFEMANURE study performed by JRC (Huygens et al. 2020). RENURE= Recovered Nitrogen from Manure, Nmin= Mineral nitrogen, NT = total nitrogen, Cu = copper, Zn = Zinc, Hg = mercury, DM = dry matter

Physical, chemical, or biological process that increases the Nmin compared to the input
Nmin/NT≥90% or TOC/TN≤3
300 mg Cu/kg DM and 800 mg Zn/kg DM
1 mg Hg/kg DM
Synchronise timing and application rates of RENURE with plant NPK requirements
Minimise NH_3 emissions during application when NH_3 or NH_4 >60% and pH is >5.5

3 Application of Business Development Package on Outreach Locations

3.1 Existing Biogas Plants

3.1.1 Biogas Bojana (Croatia)

3.1.1.1 Description of the company

Bojana is a Croatian biogas plant located in Čazna. The plant is operational since October 2014 and has with a volume of 12.000 m³ mesophilic anaerobic digesters a treatment capacity of 85.000 tonnes/year.

3.1.1.2 Business environment

The biogas plant is localised in a region characterised by agriculture and intensive cattle farming, which creates a manure surplus in this area.

The biogas plant is a synergy between three investors from which two own cow farms (2.500 cows) and 1500 ha arable land in a circle of 25 km round the biogas plant.

Spreading regulation

Croatia has recently updated its Law on Agriculture (OG i18/18, 42/20, 127/20, 52/21). However, there is no explicit mentioning of „digestate" (only manure) and its utilization in agriculture. unfortunately, digestate is seldom mentioned, and determination of its utilization is poorly described.

The use of solid manure is forbidden:

- on the ground with saturated water,
- on the snow-covered ground,
- on frozen soils and on floating lands,
- mixed with waste sludge or compost from waste sludge,
- from farms where diseases with pathogens resistant to conditions in the fertiliser pit have been identified,
- not on agricultural land.

Application of liquid manure and slurry is prohibited:

- 20 m away from lakes
- 3 m away from other water courses
- on sloping terrains where there is surface leaking
- on sloping terrains along water courses with a slope greater than 10 % at a distance less than 10 m from the water courses

There is a limited period for spreading:

1. fertilisation with manure and slurry on all agricultural areas, regardless of coverage from December, 15th – March, 15th

2. fertilisation with slurry and manure spread on the surface without entering the soil on all agricultural areas as of May, 1st – September, 1st[2].

[2] https://narodne-novine.nn.hr/clanci/sluzbeni/2021_06_73_1374.html

Phosphorus limits

Application limits / regulation for phosphorus are not officially written in legislation (personal communication IPS Konzalting, 2021) and it appears that farmers and biogas plants are also not really sure what the current rules are. There are water quality limits for directly discharging phosphorus into surface water, but this doesn't apply for Biogas Bojana.

The soils in Čazna is not rich in phosphorus (Figure 2-3) so frequently mineral phosphorus fertilisers are applied on the cultivated crops.

Nitrogen limits

During one calendar year, an agricultural holding can fertilise agricultural land with manure or manure derived digestate to a limit of 170 kg N/ha (Nitrate directive- 91/676/EEC and Decision on determining vulnerable areas in Republic of Croatia - OG, 130/2012). This rule count for the Nitrate Vulnerable Zones (NVZ): City of Zagreb, Istria, Krapina-Zagorje, Međimurje, Primorje-Gorski Kotar, Sisak-Moslavina, Varaždin, Vukovar-Srijem, Zagreb County (NN 130/2012[3]). All European Regulations and Directives apply to Croatia, albeit, since it is the youngest Member State, implementation of Directives into national legislation may take some time.

Bojana is not located in one of the NVZ and has therefore no problem to apply their digestate as such in the area.

Nutrient demand

The main cultivated crops in the region (Table 3-1) are grass, maize, wheat and soy beans fields and fruit production.

Farmers in this region use several types of mineral fertilisers during the plant season, including NPK 0-20-30, NPK 7-20-30, NPK 15-15-15, UREA (45 % N) and Calcium Ammonium Nitrate (27 %).

Table 3-1 Crops percentage (%) of UAA (utilised agricultural area: cropland + grassland) in the region of Bojana (Eurostat: Land cover overview by NUTS 2 regions, type of landcover % of UAA, 2015)

	Region Kontinentalna Hrvatska
Grassland	42,5
Cereals	25,7
Maize	13,5
Potatoes	0,3

Drivers for nutrient recovery

At the moment, disposal of digestate is no issue due to a lot of local arable land to spread it on and partner farms providing constant feedstock (cattle manure and maize).

Biogas Bojana's interest in nutrient recovery technologies is therefore not problem-driven but purely from a business perspective. They want to explore technologies that could improve their business case, making a profit, and make it more resilient towards changes (in legislation or market) in the future.

However, most large biogas plants in Croatia have two significant problems (Durdević and Hulenić 2020):

1) The market price of maize silage can have high market oscillations which represents a high share of operational costs. For Biogas Bojana, this will certainly increase costs this year (cfr. 2021), however because the feedstocks are coming from partner farms, a stable feedstock supply is secured.

[3] https://narodne-novine.nn.hr/clanci/sluzbeni/2012_11_130_2771.html

2) If the produced digestate needs to transported, this is not cost-effective to distances above 50 km. Nutrient and water removing technologies could result in digestate products that could be used within a smaller radius, thus reducing transport costs and environmental impact, and reduce an oversupply of nutrients to the soil (cfr. nutrient ratio's match more with crop demand).

Transport of digestate above 50 km is not the case for Biogas Bojana because the amount of land available around the biogas plant is sufficient to comply even with the strictest application limits (cfr. Nitrate Directive), so Bojana applies according to these limits, regardless of the obligation.

3.1.1.3 Business case evolution during SYSTEMIC

Feedstocks

Bojana receives solid cow manure from partner farms in a radius of 10 km. No gate fee is charged for the manure, only transport cost for digestate products to the land.

In 2018, 42% of the feedstock was maize silage. Over the past years, the share of maize silage has been reduced a bit and chicken manure is digested instead to reduce the costs for maize.

Waste from the milk industry is the only feedstock source that is not available close by, because it does not come from partner farms. To keep the costs low, it is only a small percentage of the feedstock mix.

Table 3-2 Origin of feedstock at Biogas Bojana

Type	**Mass /year (ktonne/year)**		
	2018	2020	2021 (estimation)
Maize silage	28	24	24
Chicken manure		2.5	2.5
Cow manure with hay (from partner farms) **Sludge and slurry from the cow farm**	37.8	35	35
Organic waste from the farm **Waste from the milk industry** **Other organic waste (e.g. biscuit factory waste, etc.)**		2.5	3
Total	65.8	64	64.5

Biogas and energy production

Each year, the plant produces 8.7 Mm³ of biogas. The biogas is converted in two CHPs with a capacity of 1 MW each.

Concentration of hydrogen sulphide (H_2S) in the biogas is kept under the 200 ppm (~120 ppm) with aerobic bacteria by injecting O_2 the H_2S is transformed to S, which precipitates and by addition of an additive which binds H_2S.

In total 18,000 MWh of electricity is produced per year, from which 5-7% is used on site and 92% is put on the grid. 7,000,000 kWh heat per year coming from the residual heat of the CHP is used to warm up the digesters.

Since 2020, Biogas Bojana purchased a belt dryer with a chopper and steal belt that is able to dry maize and the solid fraction of digestate. This way, up to 100% of the heat from the CHP can be reused when the dryer is running (10,000,000 kWh th per year).

Digestate treatment cascade

In mixing pit 1 (150 m³), the feedstocks from the collecting pit, digestate from digester 1 and maize silage is homogenised. This mixture is pumped into digester 1, where anaerobic digestion produces biogas from 92-95% of the feedstocks during a retention time of 23 days.

The digestate is then transferred to digester 2 (i.e. post-digester), where it also remains 23 days. If it is necessary to obtain more biogas in a shorter period of time, substrates from the mixer pit can also be pumped directly into digester 2.

The digestate from digester 2 is separated into a solid fraction (solid digestate) and liquid fraction with a screw press (without the use of flocculants). The solid fraction is stored in a container (trailer). The liquid fraction goes back to the collecting pit and is recycled back to the digesters.

In mixing pit 2, maize silage and liquid fraction of digestate and slurry from the farm is homogenised. The mixture is pumped into digester 3 and anaerobic digestion takes place during 50 days.

The remaining digestate is also separated with the same screw press.

The liquid fraction goes back to mixing pit 2.

The belt conveyor dryer has been installed as a multi-purpose tool for drying a varied range of materials: cereals during harvest and then dry straw, forage crops, herbs, woodchips, manure and solid fraction of digestate.

Biogas Bojana plans to dry cereals in summer and solid fraction during the rest of the year. No solid fraction has been dried, since drying cereals is currently still the most cost-effective use for the dryer.

Table 3-3 Average composition of the end products at Biogas Bojana (2020 and 2021 estimation), including nitrogen (N), phosphorus (P) and potassium (K).

Input		Digestate	
After		Screw press	
Product	Digestate	Liquid fraction	Solid fraction
Mass (kton/year)	65.6	55.5	10
pH		7.91	8.58
Dry matter (%)	7.2	5.6	26.7
N total(Kj-N) (g N/kg)	3.7	3.3	5.8
NH_4-N (g N/kg)	1.2	1.2	1.1
P total (g P/kg)	0.9	0.7	2.08
K total (g K/kg)	2.0	1.95	2.09

Labour

Biogas Bojana has 4 employees to operate the biogas plant.

Destination of the end products

Biogas Bojana has half year storage capacity for digestate products during winter.

In periods when there is a demand for raw digestate as fertiliser (f.e. during summer), it is used as such.

In periods when digestate spreading is not allowed (f.e. a few weeks in summer on certain crop cultivations, in wintertime), the digestate is separated with a screw press:

- The liquid fraction is recycled in the process and if the weather conditions allow it, it is spread on the 1,500 ha of partner lands as alternative for mineral fertiliser. The transport is maximum 50 km on the road, 25 km in a circle around the farm.
- The solid fraction digestate is collected in a container (trailer) and used for fertilisation or is mixed with straw and reused as bedding material for the cows at the partner farms. This is an important for them to avoid the cost of straw. With implementation of the dryer, the dried solid fraction has also improved in quality as bedding material for cows.

SWOT analysis Biogas Bojana

Strengths

- Cooperation with 4 partner farms: favourable exchange of digestate and substrates (maize).
- Currently no strict nutrient application limitations on surrounding agricultural soil.

Weaknesses

- Unclear legislation for application limits.

Opportunities

- Anticipating on new technologies for NRR could provide them a competitive advantage towards manure and digestate.

Threats

- Prospect of stricter legislation on nitrogen, phosphorus and possibly also emissions.

3.1.1.4 Suggestion done in SYSTEMIC and BDP

Bojana would like to be prepared for future stringent nutrient regulations (e.g. inclusion as NVZ cfr. Nitrate Directive) and continue to have the business running profitably. For this reason they have been involved in SYSTEMIC, to discover and explore technologies to further optimise their business case and reduce transport costs of digestate.

Ideally, in the mindset of nutrient recycling and to be prepared for the possibility of a stricter legal framework on nitrogen emissions and application on land, the liquid fraction of digestate could be cleaned with an **N-stripping-scrubbing installation**. In this way the nitrogen can be recovered as ammonium sulphate solution (a single nutrient fertiliser) and an odour free digestate creating lower N emissions. AS could be a good fertiliser for filling in the nitrogen demand of grass, maize and cereals, the main cultivated crops in the region (Table 3-1). An extra advantage would be that solid fraction from the N stripped digested, would contain less ammonia and contribute to better animal welfare when reused as bedding material for cows.

The simulation in ANNEX

I.1.1 Nitrogen stripping-scrubbing" performed by the NUTRICAS Tool resulted in 3,082 tonnes of AS solution per year (96 g $(NH_4)_2SO_4$/ kg AS solution) and 62,748 tonnes of N stripped digestate. To be break even with the CAPEX and OPEX costs for such NRR technology, a price of 1.1 - 1.3 €/tonne of AS or N stripped digestate (including transport and application costs) should be required from farmers who would like to use these products. In theory, this seems feasible because farmers in the region currently use several types of mineral nitrogen fertilisers during the plant season.

However, the use of AS is still unknown in Croatia and farmers would be reluctant to use this unfamiliar product, let alone would the adjusted application conditions and machinery for low-emission spreading be available (i.e. close to the soil or plant base like injection, spoke wheel application, trail hoses, etc.).

Thus, currently there is no interest in ammonium sulphate solution in Cazna region, unless the use of mineral N fertilisers is restricted by regulations or if Bojana is prepared to invest in an education and demonstration programme for farmers, convincing them of the added value of AS as alternative for replacement of mineral N fertilisers. They could also try to set up their own contracting service for applying this bio-based N fertiliser on farmers' land, hereby overcoming the technical limitations and making it easier for farmers to use the product.

The simulation with the **FiberPlus system** (see ANNEX I.1.2 Fiberplus N stripping-scrubbing"), proved to be more expensive (up to 1.9 - 2.3 €/tonne of AS, N stripped digestate and calciumcarbonate ($CaCO_3$) to be break even with the yearly CAPEX and OPEX costs). Also, a source of cheap, recovered gypsum (like flue gas desulphurisation gypsum) was not present in the surroundings of the biogas plant.

For both N stripping-scrubbing cascades, the final AS should be compatible with the proposed criteria for RENURE (Table 2-1). Which would make it possible in the future to apply above 170 kg N/ha per year of manure derived nitrogen in NVZ (see Chapter 4).

Additionally, with installation of the belt dryer there is no longer residual heat available from the CHPs that could be used in the N stripping-scrubbing installation. A detailed balance should be made if N stripping-scrubbing (including marketing and spreading of the end products) would be more profitable than the current practice (drying of solid fraction or maize) to be worth the investment. If so, the dryer should start working on natural gas which would be profitable from an economical point of view, but not environmentally sustainable.

The amount of land available around the biogas plant is currently sufficient to comply even with the strictest application limits (cfr. Nitrate Directive), so Bojana applies it according to these limits, regardless of the obligation. SYSTEMIC could only advice to spread the liquid fraction of digestate only in relation with crop demand (not during 5-6 winter months), to prevent the risk of leaching the nutrients (N and P) to the soil and groundwater.

In their current business- and agricultural environment there is currently no economic driver yet for Bojana to implement technologies such as N stripping-scrubbing or membrane filtration, evaporation, etc.

3.1.1.5 Impact of SYSTEMIC

Biogas Bojana has been actively involved in SYSTEMIC because they believe that when it comes to knowledge, you can never gather it too much.

The (international) contacts they have established through the project and the knowledge they were able to adopt were invaluable.

Although most of the technologies they have become acquainted with thanks to the project, are for economic reasons not yet interesting for their plant. However, it gave them a head-start for when these technologies would become financially interesting for them in the future, for example if national regulation will change.

On the other hand, there were also many direct impacts of SYSTEMIC on their business case. For example, they received information about different suppliers of drying systems and the pro's and con's of the dryer they were planning to buy, so they were able to make a more considered choice. Likewise, when they encountered a biological problem in the digester, they were able to get a second opinion from the SYSTEMIC consortium (and the network of biogas plants) on the advice provided by their regular consultant. Hereby they gained knowledge about what eventually was the source of the problem and how to prevent it in the future.

In the end, Bojana found the plant visits with and to SYSTEMIC biogas Demo Plants were the most inspiring. They are sure that currently they have used only a small part of the knowledge and network they gained with SYSTEMIC and that much more of this will become useful in the future.

3.1.1.6 Future plans

Even though Croatia still does not have standards related to greenhouse gas emissions that encourage Renewable Energy Systems (such as biogas), and agricultural industry is not a topic of the EU Emission Trading System (ETS), these fields will be significant in the near future, due to the goals set by European Union to reduce the negative impact of climate change and decarbonization of each sector (Durdević and Hulenić 2020).

Additionally, feed-in-tariffs are getting lower and dairy farming is starting to expand in the area, which implies that a higher anaerobic digestion capacity will be needed and consequently also higher volume of digestate to dispose of.

Bojana is therefore always trying to be up to date about changing legislation and emerging technologies to be able to respond quickly when the time comes. Yet for now, their business case is doing well, including circular and regional use of substrates. The end products from digestate are used on the biogas plant's own land and on the land of the partner farms.

3.1.2 Ferme du Faascht (Wallonia, Belgium)

3.1.2.1 Description of the company

The biogas plant in Attert, Belgium, is located on the Faascht cattle farm with 300 cows and built in 2003 by the family Kessler. Back then, agriculture in Wallonia was in a crisis, farmers' incomes fell and the Kesslers saw energy production as an opportunity to escape this because of the stability of the electricity market.

Their project was supported by the non-profit organization Pays de l'Attert and several INTERREG research projects. Since 2015, the company has been taken over by the second generation, Mélody Kessler, her husband Ludovic Peter and their partner David Feller. They continue to develop an agricultural model based on circular economy through various research projects and through diversification towards sustainable horticulture. Today, the farm has - next to the biogas plant - 150 dairy cows, 90 calves and 60 meat cattle.

3.1.2.2 Business environment

Ferme du Faascht is located in the south of Wallonia which has a high livestock density (Figure 2-4).

For the application of nitrogen rich end products from digestate, they are already searching for alternatives in case their region in Wallonia is to become a EU nitrate vulnerable zone in the future. They focus therefore first on acquiring the authorization to spread the digestate in the Grand Duchy of Luxembourg and then on technologies to reduce the N content by e.g. biological treatment, but investment in production of nitrogen-potassium (NK) concentrates or scrubber salts complying with RENURE criteria would be a more sustainable option.

In general, they want to maximise the circular principle on the farm because they believe in the economic and ecological benefits on the long term. Therefore, they are investigating the different possibilities regarding stable biogas and green energy production and reuse of feedstocks, end products, heat, CO_2 and water, combined with animal welfare and sustainable and local tomato cultivation.

Spreading regulation

An average quantity of organic nitrogen applicable per year and per hectare of pasture or meadows is a maximum of 230 kg N. Restitution to the soil by grazing animals is taken into account in the organic and total nitrogen inputs. The annual contribution of total nitrogen (organic + mineral) per hectare is a maximum of 350 kg N.

Over the rotation (2-5 years), the average quantity of organic nitrogen applicable per year and per hectare of arable land is a maximum of 115 kg N. For each plot the maximum quantity of organic nitrogen applicable is 230 kg N/ ha. The annual total nitrogen input (organic + mineral) is a maximum of 250 kg N/ ha.

The periods during which spreading is authorised depend on the type of fertiliser used at the farm, the location of the plot (in a vulnerable area or not) and its destination (arable land or meadow/grassland).

Any application of organic or mineral fertilisers must meet the requirements depending on incorporation, soil conditions (frozen, wet, slopes), after certain crop cultivation[4].

The nitrogen contained in the digestate, although it is largely in the form of ammonium (NH_4^+), is limited most because it falls under the category of liquid organic fertilisers. Also, since 1st of January 2015, wide-spreading of manure with "nozzle vane not inverted" with barrels of a capacity greater than 10,000 liters is prohibited.

Phosphorus limits

In Wallonia there are no specific limits for phosphorus application on land.

Nitrogen limits

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territory of Wallonia, with
the territory (
Figure 3-1).

In vulnerable areas, the average quantity of organic nitrogen supplied per hectare of the entire farm (crops and meadows) cannot exceed 170 kg N/ha. Also, spreading manure and compost is prohibited from 1st October to 15 November and on frozen ground.

The region where Ferme De Faascht is located is currently not designated as a nitrate vulnerable zone.

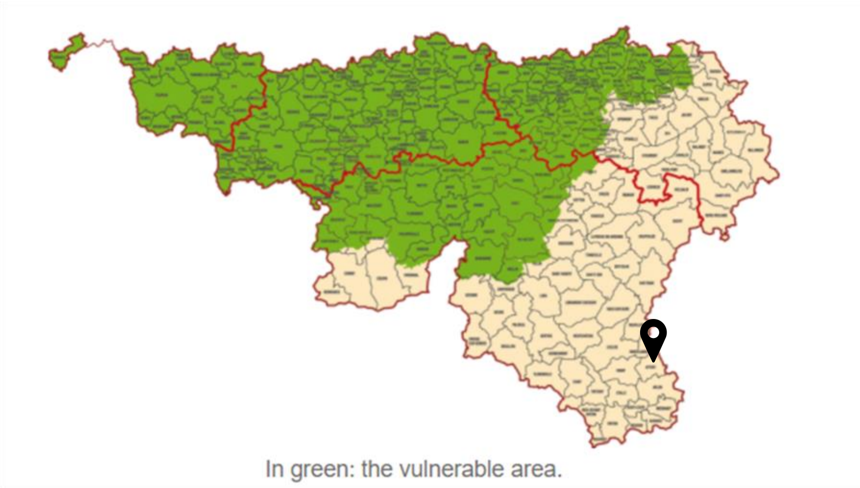

Figure 3-1 EU Nitrate Vulnerable Zones in Wallonia. It covers areas where the nitrate content of groundwater exceeds 50 mg / l or is at risk of exceeding them and areas which contribute to the eutrophication of the North Sea. Source : https://protecteau.be/fr/agriculteurs/zones-vulnerables

Nutrient demand

Digestate as such is a valuable fertiliser with readily available nitrogen, that fits well with the nutrient demand of grass and maize, the most dominant crop cultivated in the region (Table 3-4).

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[4] https://protecteau.be/fr/nitrate/agriculteurs/epandage#conditions

Table 3-4 Crops percentage (%) of UAA (utilised agricultural area: cropland + grassland) in the region of SCRL Kessler, including surrounding regions in Belgium, Luxembourg and France (Eurostat: Land cover overview by NUTS 2 regions, type of landcover % of UAA, 2015)

	Wallonia (BE)	Luxembourg (BE)	Luxembourg (LU)	Est (FR)	Lorraine (FR)	Campagne-Ardenne (FR)
Grassland	56.0	79.6	55.4	53.8	47.0	26.8
Cereals	28.5		33.7	33.1		
Maize	6.3		6.9	11.6		
Potatoes	4.4			0.3		
Sugar beet	3.4			0.3		

3.1.2.3 Business case evolution during SYSTEMIC

Feedstocks

Manure from the farm's own dairy cows and meat cattle is digested and grass, energy rich waste from the dairy industry, biological waste from the supermarkets, food industry (f.e. chocolate factory waste) and low energetic organic waste such as vegetable residues are imported from the area (radius of 40 km) (Table 3-5).

A relatively cheap, simple and robust loading system for solid feedstocks is installed: a hydraulic scraping system with no mixers or screws that can get blocked. It loads the feedstocks into the digester.

The liquid feedstocks are stored in storage silo's.

In 2021, the processing capacity of the biogas plant was extended (reactors, storage, hygenisation units, CHPs) to be able to digest more feedstocks in the future.

Table 3-5 Origin of feedstock at Ferme du Faascht

Type	**Mass /year (ktonne/year)**			
	2018	2019	2020	2021-...
Cattle manure	5	6.6	6.6	
Maize		1.4	1.4	
Biological waste supermarket	11	12	11	
Waste from food industry	5		2	
Waste from dairy industry			1	
Low energetic organic waste			1	
Total	20	20	23	Increased capacity

A central pumping station is installed for distribution of all liquid streams (feedstocks, digestate). There is no direct contact between the pumps and the liquid, which makes it also very robust and low in maintenance.

Since an extension of the plant in 2021, there are four digesters available (750m³ + 2400m³ + 3500m³ + 3500m³) and a post digester (750m³) working under mesophilic conditions and providing a residence time up to 80 days.

The digesters are used in series with recycling loops between the digesters: the pumping system pumps the feedstocks to the 1st digester, where feedstock is mixed with digestate from the post-digester. Because of the relatively high organic loading rate in digester 1, the quality and amount of the biogas is low. Therefore, the digestate and biogas from the 1st digester goes to the 2nd, and extra feedstock is added. This principle continues throughout the 4 digesters and post-digester, creating a stable feed pattern throughout the AD and giving less peaks in biogas production and a better biogas quality.

Biogas production

The produced biogas is stored in the balloon roof of each digester after which it is cleaned with a desulphurisation unit and since the extension in 2021, there are six CHP units to valorise biogas with capacity of 2.4 MWel (190 kW + 360 kW + 3600kW and 3 x 500kW).

Digestate treatment cascade

The digestate is separated with a screw press.

- The liquid fraction is sanitised (1h 70°C) in hygenisation tanks of 4000 m^3.
- The solid fraction is stored in a non-covered storage (4500 m^3).

Digestate can be dried on a band dryer with maximum capacity of 4 ktonne per year using 5,000 MWh thermal energy per year. This dryer can reduce the digestate volume with 63%, yet currently (anno 2021) it is not operational.

Table 3-6 Composition of the end products at Ferme du Faascht (2020- 2021 estimation), including nitrogen (N), phosphorus (P) and potassium (K).

Input		**Digestate**		
After		Belt dryer	Screw press	
Product	Digestate	Dried digestate	Liquid fraction	Solid fraction
Mass (ktonne/year)	16	0	13	0.6
Dry matter (%)	9	90	5	30
N total (g N/kg)	7.6	30	6	5
NH_4-N (g N/kg)		0	3	0.05
P total (g P_2O_5/kg)	1.87	23	0.7	6
K total (g K_2O/kg)	3.9	60	2.3	1

Labour

Currently, Mélody, Ludovic and their associate David are running the farm and biogas plant, together with five other employees. With the horticultural project (3.1.2.6 Future plans) and the extension of the biogas plant, minimum seven others employees are in the process of being hired.

Energy - CHP

In 2020, 6,600 MWh per year was produced. From the 6000 MWh electricity produced, less than 10% is used on the Faascht farm and 90% went to the grid, providing green electricity needed for half of the community of the Attert municipality.

Since 2021, with the additional CHPs, the plant can produce between 18,000 and 20,000 MWh el and 20,000 MWh th per year. About 40% of this heat is used on site to heat the farm, dairy farm and buildings (5%), for hygienisation of the digestate (10%) and for drying digestate and wood (15-25%). Still 12,000 MWh th is available to be reused (see 3.1.2.6 Future plans).

Destination of the end products

The farm has 120 ha of own land of which 95% are meadows.

The hygenised liquid fraction of the digestate is used on surrounding grass land (15% on the 120 ha of the farm's own land), the rest is used for maize culture.

The solid fraction is used on their own lands. From 2023, this fraction will be used as a growing medium for the tomato cultivation in the greenhouse at Faascht.

The dried digestate pellets can go to horticulture as organic fertiliser.

SWOT analysis of Ferme du Faascht

Strengths

- The digestate is hygienised. This allows them to be able to promote it beyond the Belgian borders.
- A lot of grassland is available in the area
- Faascht is not located in a Nitrate Vulnerable Zone.

Weaknesses

- Far from activity centres, which renders higher transport cost from other biological wastes like food waste, supermarket waste etc.

Opportunities

- Development of the use of separated or dried digestate fractions in horticulture.
- Extended capacity of the biogas plants to produce more biogas.

Threats

- A lot of competition on input feedstocks due to the development of anaerobic digestion in nearby France.

3.1.2.4 Suggestion done in SYSTEMIC and BDP

In the EU Interreg project PERSEPHONE, in which Ferme du Faascht was involved, amongst other things the value of raw digestate as a fertiliser and soil improver was intensively studied and tested. Based on these positive project results, Ferme du Faascht is keen to see organic nitrogen from raw digestate recognised as less polluting for soils and water than mineral nitrogen from fossil fuel based artificial N fertilisers.

Ferme du Faascht is already searching for alternatives in case their region in Wallonia is to become a nitrate vulnerable zone in the future. They focus was therefore first on acquiring the authorization to spread the digestate in the Grand Duchy of Luxembourg and then on technologies to reduce the N content by e.g. biological treatment. However, investment in production of scrubber salts or NK concentrates complying with RENURE criteria would be a more circular and sustainable option.

For the hygenised liquid fraction of digestate, Ferme du Faascht is interested in the management and reduction/recovery of nitrogen to be prepared for possible stricter nitrogen application limits in the future.

From this starting point, two simulations were performed with the NUTRICAS Tool: N stripping-scrubbing and FiberPlus N stripping-scrubbing on the liquid fraction of digestate (see ANNEX I.2.1 Nitrogen stripping-scrubbing” and ANNEX I.2.2 Fiberplus N stripping-scrubbing”).

N stripping-scrubbing would produce yearly 624 tonnes of ammonium sulphate (AS) (5% N) and 12,490 tonnes of N stripped liquid fraction (LF) (3.7% N). If a nitrogen application limits of 170 kg N/ha per year would be introduced in the Attert region (cfr. NVZ), the volume N stripped LF could be spread on ± half the surface of land compared to unstripped liquid fraction. The AS would be a good alternative for mineral N fertilisers, with the sulphur content having an added fertiliser value for grassland in particular. However, sulphur administration as nutrient should happen responsibly, because, too high levels of S can have negative impacts on crops, soils and groundwater quality for drinking water production. According to the simulation, the AS would comply with the RENURE criteria (Table 2-1) for mineral N content and total organic carbon. To cover the CAPEX and OPEX, revenues from AS and N stripped liquid fraction should be around 1.5 - 1.9 €/tonne, which could be feasible.

The **FiberPlus system** would not be an economical solution, because of its higher investment costs and operational costs and the lack of a cheap and local source of recovered gypsum available in the region of Faascht.

The production of RO concentrates with **membrane filtration and reverse osmosis** was simulated in ANNEX 0. Since the permeate after microfiltration would have too high dry matter content (2.1% DM) to be further purified economically in a reverse osmosis unit, this permeate should first be diluted (factor 1:2.25), which would require 9,620 m³ of dilution water per year. For this RO permeate (4,188 tonnes per year) or ion exchange (IE) purified water (4,146 tonnes/ year) could be used in combination with rainwater collected in the 3,400 m³ lagoon. However, the rainwater was initially meant to irrigate the tomatoes in the greenhouse. Recirculation loops were not included in the NUTRICS Tool, so the water mass balance and effect on the separation efficiency of the RO would need to be investigated further in practice before making the decision on the investment. Technically, the quality of the RO permeate would be sufficient to irrigate the tomatoes, so IE for reaching discharge limits on surface water would not be required.

This would render cost of the whole membrane filtration cascade (without IE) to 2.1 - 2.7 €/m³ of liquid fraction or 1.7 - 2.2 €/m³ of digestate.

For all simulations, a detailed heat and water balance should be made so see if there would be enough heat, green electricity and water available to sustain the suggested processes and the new foreseen activities at Ferme du Faascht (3.1.2.6 Future plans).

3.1.2.5 Impact of SYSTEMIC

Participating in the SYSTEMIC project was an opportunity for Ferme du Faascht to be able to interact with biogas plants throughout Europe and to strengthen our network. They have seen that digestate recovery issues still remain an important point whatever the region and that there are improvements to be made in terms of regulations.

During SYSTEMIC, Ferme du Faascht has discovered other technologies, often complex, to enhance and manage digestate. Many technologies must sometimes be implemented, simply to meet the regulations while the current practice of recovery of organic matter can be done very easily by adding raw digestate to the soil. It is seen everywhere in Europe that digestate is not considered at its fair value for the development of sustainable agriculture. Digestate lacks "marketing" visibility and still suffers from the image of waste that must be removed, while the recycling of the nutrients it contains is essential for to implement a circular economy model for agriculture and ensure environmentally safe application of the nutrients as fertilisers.

There is still a high risk to implement complex recycling technologies, partly because given the present situation it is inefficient from an energy and economic point of view, and partly because new products are produced that are unsupported from a legislative point of view. The complexity and economical risk of these technologies still conflicts with the autonomy of agricultural producers, a central issue for the food sovereignty of the regions.

3.1.2.6 Future plans

Algae production and increased methane content

Ferme de Faascht has been participating in the EU Interreg Grande Région project PERSEPHONE. In this framework they were testing the use of CO_2, heat and liquid fraction of digestate for algae cultivation.

Also the principle of bio-methanation[5] ($4H_2 + CO_2 \rightarrow CH_4 + 2H_2O$) combined with AD to increase the methane production, was investigated during this project.

If this process would be technically and economically feasible on full scale, Ferme du Faascht wants to investigate the production of hydrogen (H_2) by solar panels (for example, trials were done in the Solhyd[6] project) to create a biogas with high % of methane. This could then be compressed as bio-CNG and used for tractor fuel.

The production of bio-methane is currently not an option, because the closest gas network is located 10 km from the plant.

Tomato cultivation

Ferme du Faascht is currently (2021) building a greenhouse for tomato cultivation, which should be ready in February 2022. The Centre Interprofessionnel Maraîcher (CIM) in Gembloux investigated that a greenhouse of at least 1 ha would need to efficiently reuse the available residual heat form the 6 CHPs.

Here they would be cultivating 600 tonnes of tomatoes per year because of two alternating cultivation cycles per year.

The tomatoes will also require a large water supply. Therefore, all the rainwater from the roofs and concrete and waste water are collected separately: wastewater goes back to digesters and the rainwater is collected in a newly build storage tank of 3,400 m^3. It will be pumped to the greenhouse, and the pumps are powered by green electricity. This amount of water would be enough to provide to tomatoes with rainwater whole year round, even in years with dry summers.

The residues from tomatoes and tomato plants will be used as feedstock for the AD.

In the first year, some testing will be done with using the solid fraction of digestate as a growing substrate and fertiliser for the tomato plants. After harvesting, the spent "growing substrate" is recycled to the digesters and solid fraction is used again the next cultivation cycle.

Ferme du Faascht has had exploring discussions with BENAS Gruppe- GNS-Magaverde (SYSTEMIC Demo Plant in Germany) to test the use of digestate-fiber-made planting boxes for the tomato plants.

Eventually, they would also like to recover CO_2 from biogas (60% CH_4 and 40% CO_2) and inject it in the greenhouse, because the growth of tomatoes in greenhouses requires is additionally stimulated by CO_2.

The new greenhouse will render seven extra jobs on the farm.

3.1.3 Biogas Bree (Flanders, Belgium)

3.1.3.1 Description of the company

Biogas Bree is a Belgian biogas plant, located in Bree, in the province of Limburg near the Dutch border.

The plant was built in 2011 and started production in 2013. They operate mesophilic digestion in 13,500 m^3 digesters and post-digesters. This includes a digester for animal manure, completely separated from the organic waste digesters.

The plant is run by André Schelfhout and his three sons, who now since a few years have been running and operating the plant themselves more independently from their father.

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[5] https://systemicproject.eu/systemic-attends-colloquium-of-the-interregg-project-persepohone/

[6] https://solhyd.org/en/

3.1.3.2 Business environment

The region (North-East Limburg) is characterised by intensive livestock farming, mainly pigs and cattle. Like in almost all provinces in Flanders, the soil is rich in phosphorus and strict national fertilisation limits contribute to a surplus of manure in this area. Phosphorus is typically the first limiting factor when fertilising in Flanders (north of Belgium) with manure products followed by limitation due to the nitrogen content of manure products (cfr. Figure 2-2 and Figure 2-3). In addition, Flemish manure (derived products) are not allowed to be used in Wallonia (southern part of Belgium).

Spreading regulation

The Flemish Manure Decree is the transposition of the European Nitrates Directive in Flemish legislation. It defines fertilisation restrictions for nutrients (N and P) that can be applied on Flemish soils for different types of fertilisers: animal manure, mineral fertilisers and other fertilisers.

If manure is co-digested, the digestate is considered as 100% manure and must be applied according to the fertilisation restrictions for "animal manure". If no manure is digested, the digestate can be applied according to the fertilisation restrictions for "other fertilisers". The application of these fertilisers on arable lands not permanently covered is banned from 1 September to 15 February. In addition, application is also banned at night and on Sundays and public holidays and, in coastal areas, on Saturdays, except for chemical fertilisers. Derogations are possible for manures and composts (prohibited application only from 15 November to 15 January), or even for nitrogen-fixing intermediate crops, which may benefit from a time lag.

Phosphorus limits

Agricultural soils are categorised into four groups, depending on the plant available P in the soil, expressed in mg P/100 g soil. The amount of plant available P needs to be analysed by an accredited laboratory. Per P status soil class, different P application limits for fertilisation apply.

Nitrogen limits

Flanders is completely located in a Nitrate Vulnerable zone, and therefore has to comply with the EU Nitrate directive, when regarding animal manure-digestate (Figure 2-2). The standards for the other fertilising products are based on 'effective N' and differ for each (group of) crop(s) and per type of soil (sand/other). The effective N is the amount of total N applied that is expected to be available for crop uptake in the season of application. It is calculated based on legally imposed N working coefficients.

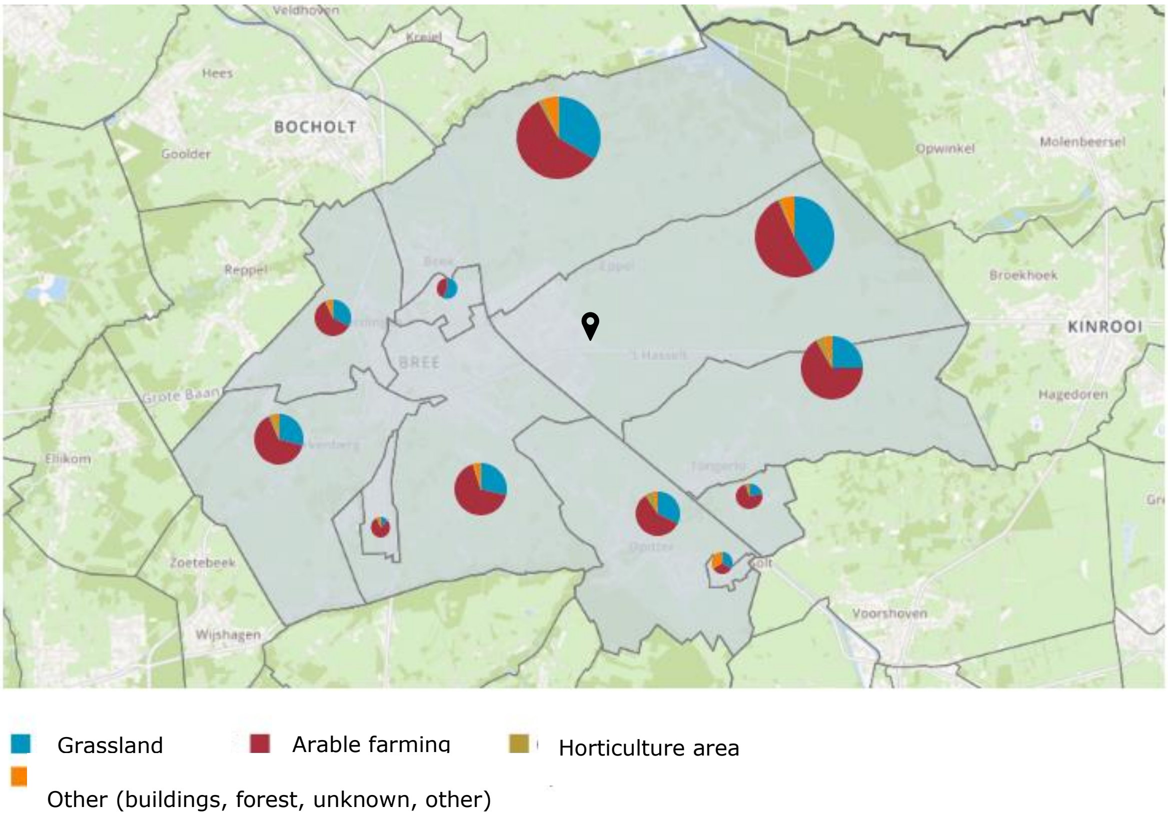

Figure 3-2 Surface agricultural area in 5 culture categories (2020). Source: map 6, Department Agriculture and Fisheries, Agricultural use area, provincies.incijfers.be

Nutrient demand

As can be seen on the map, the area around Bree is characterised mainly by arable farming (cereals and maize) and grassland. For the regions near Biogas Bree (±100km), cereals, maize and grassland cover a substantial amount of the agricultural land (Table 3-7).

Table 3-7 Percentage (%) of UAA (utilised agricultural area: cropland + grassland) for different crops in the region of Biogas Bree, including regions in Belgium, Germany and the Netherlands. Source: Eurostat: Land cover overview by NUTS 2 regions, type of landcover % of UAA, 2015

Region Biogas Bree						
	Flanders (BE)	Limburg (BE)	Northrhein-Westfalen (DE)	Region Köln (DE)	Zuid-Nederland (NL)	Limburg (NL)
Grassland	47.7	44.1	42.1	51.1	50.0	49.4
Cereals	30.1		44.3		28.7	
Maize	20.4		17.4		21.7	

Cereals like winter wheat require a fertiliser with concentrated N and no to very little P and K (Harms et al. 2019).

Maize requires relatively high nitrogen and potassium, in the start and during the growing stages with low amounts of phosphorus. Yet, a start fertilisation with P is frequently done, although it is only necessary when a soil has a low P content or an acidic soil or if the early spring was cold and wet (Abts et al. 2016).

Grass requires substantial amounts of N (in spring and summer), potassium and sulphur.

3.1.3.3 Business case evolution during SYSTEMIC

The plant is operational since 2013 and has a treatment capacity 85,000 tonnes/year.

Feedstocks

Pig manure is first dewatered by evaporating the water, by and in-house designed evaporation or "thickener" system comparable to the concept of a spraying dryer (cfr. milk processing industry). This thickener can evaporate 1.3 m^3 of water per hour and has been also certified as hygienisation method. The sanitised manure is anaerobically digested producing sanitised digested manure.

Table 3-8 Origin of feedstock at the Biogas Bree anaerobic digestion plant in Flanders (Belgium)

Type	Mass/year (ktonne /year)	
	2017-2018-2019	2020 and 2021
Pig manure (3-6% DM)	25	23
Evaporation of water	20.8	
Thickened pig manure (18% DM)	4.2	11.5
Pig manure (3-6% DM)		4
Agriculture related products	26	24
Maize crops	15	
Grain, beet, apple residues	11	
Organic biological waste: Industrial WWT sludge, molasses, supermarket mix, etc.	34	34
Total	85	85

Biogas production

Due to the high quality of the feedstock, 1,500 m^3 of biogas is produced per hour, resulting in 12.7 Mm^3 of biogas every year.

Digestate treatment cascade

In 2017, the 4.2 ktonne thickened pig manure was combined with some agriculture related crops and digested to produce 9.2 ktonne "animal-related" digestate. This was dried in a belt dryer to 1.5 - 2 ktonne.

The 43 ktonne 'vegetable' digestate was separated with a decanter centrifuge (with addition of polymers) to remove the phosphorus from the liquid fraction.

The air from the thickening system and the belt-dryer is scrubbed by a combi-air washer (acid and biological) and a bio-bed, producing ammonium sulphate solution (±70 g N/kg and 80 g S/kg, pH 3.5).

Table 3-9 Composition of the end products at Biogas Bree (2017-2018-2019) for the animal digestate and vegetal digestate, including nitrogen (N), phosphorus (P) and potassium (K).

Input per year	4.2 ktonne thickened pig manure + 5 ktonne agricultural residues	9.2 ktonne "Animal related" digestate		43 ktonne "Vegetal" digestate	
After		Belt dryer		Decanter centrifuge	
Product	**"Animal related" digestate**	**Dried "Animal related" digestate**	**"Vegetal" digestate**	**Liquid fraction**	**Solid fraction**
Mass (kton/year)	9.2	1.5-2	43	37	6
Dry matter (%)		92		8	30
N total (g N/kg)		20	6.5	6.5	6.5
P_2O_5 (g P_2O_5/kg)		35	4.5	2.17	10
K total (g K/kg)		44	4.5	5.5	

Throughout the SYSTEMIC project (and already before), Biogas Bree has been exploring which end products would be better marketable and how to produce them. Therefore, they have been constantly investigating and testing multiple technological improvements in their digestate treatment cascade (see 3.1.3.4 Suggestions and advice provided in SYSTEMIC).

Since 2020 (Table 3-10), 23 ktonne pig manure is thickened in the evaporation/thickening system and digested to 11.5 ktonne "manure digestate". From this, 10.5 ktonne go to the fluidised bed dryer.

About 4 ktonne pig manure (not thickened) is combined with 5 ktonne agriculture residues and digested to produce 9 ktonne "animal-related" digestate.

The 58 ktonne 'vegetable' digestate is separated with a centrifuge (with addition of polymers) into 52.5 ktonne liquid fraction to the 5.5 ktonne solid fraction.

By mixing the manure and animal- related digestate and liquid fraction of vegetal digestate and drying this in a fluidised bed dryer dried organic soil improver is obtained.

The air from the thickening system and the fluidised bed dryer is scrubbed by a combi-air washer (acid and biological) and a bio-bed, producing 1.5 ktonne ammonium sulphate solution (±90 g N/kg and 100 g S/kg, pH 7) per year.

Table 3-10 Composition of the end products at Biogas Bree (2020-2021) for the animal digestate and vegetal digestate, including nitrogen (N), phosphorus (P) and potassium (K).

Input	23 ktonne pig manure	4 ktonne pig manure and 5 ktonne bio-waste	29 ktonne biowaste + 24 ktonne agricultural residues + 5 ktonne run off water	58 ktonne "Vegetal" digestate		Manure digestate + "Animal related" digestate + LF vegetal digestate
After	Thickener and "manure digester"	"Animal related digester"	"Vegetal digester"	Centrifuge		Fluidised bed drier
Product	**Manure digestate**	**"Animal related" digestate**	**"Vegetal" digestate**	**Liquid fraction**	**Solid fraction**	**Dried "Animal related" digestate**
Mass (ktonne/year)	11.5	9	58	52.5	5.5	3
Dry matter (%)	6-15	12	9	8	28	90
N total (g N/kg)		5.2	5.5	6	10	30-100
P_2O_5 (g P_2O_5/kg)		5	2.8	2	12	30
K total (g K/kg)		7	4.3	5	6	60

Labour

The biogas plant is run with five full time equivalents (FTE) and five FTE's that are subcontracted or provide transport and maintenance activities.

Energy

The biogas is converted in 3 CHP engines (total capacity 3.6 MW el and 4.2 MW th) into in total 26,000 MWh electricity per year. About 6% of the electricity produced (1,560 MWh) is used on site and 94% is put on the grid (24,440 MWh).

In 2017-2019, all heat from the CHP was reused in the evaporator/thickener (1350 kW) and the belt dryer (2700 kW).

In 2020, the fluidised bed dryer was purchased and installed to replace the belt dryer. It also uses heat from the CHP (31,500 MWh). Green electricity is required to keep its ventilators and coolers active (370 kW).

Destination of end products

In 2017, the liquid and solid fraction of the vegetal digestate are used on Biogas Bree's own lands (100 ha) or sold (negative value) in Flanders to arable farmers directly or indirectly through contractors.

The digested manure and dried animal digestate was sold across the border as a fertiliser in Germany and the Netherlands.

In 2019-2020, Biogas Bree produced a dried, granulated organic soil improver from the animal digestate, which they market in big bags to farmers and in re-usable plastic buckets to gardeners as 'Viridius' (2N/4P/5K and 1.5 MgO), ideal for grass, buxus, roses, flowers, as alternative for dried cow or horse manure.

Figure 3-3 Viridius product and branding of Biogas Bree's dried soil improver granules. www.viridius.be

Ammonium sulphate solution is exported across the border as a N/S fertiliser or locally used in Limburg in to demonstrate and boost the use of this product as efficient fertiliser for grass and maize in the framework of the "Flanders Circular" project "UNIR" (more details in Chapter 3.1.3.4 Suggestions and advice provided in SYSTEMIC).

In 2021, the 1 ktonne of hygenised manure digestate (only 5% of the total volume of manure digestate) is still exported across the border to Germany.

With 13.5 ktonne per year a blend is made of 50% liquid fraction of vegetal digestate and 50% manure- and animal digestate and dried in the fluidised bed dryer as organic soil improver granules (i.e. Viridius, but with more tailored nutrient ratios and a better pellet shape), which is exported to France where it is used as a fertiliser (3N/3P/6K), ideal for grass, roses and vineyards.

The remaining 39 ktonne liquid fraction of vegetal digestate that is not send to the dryer is partly used as fertiliser on local Flemish fields and partly exported to the Netherlands as 'soil improver'.

SWOT analysis of Biogas Bree

Strengths

- Region close to the border with the Netherlands and Germany.
- Dried product with high potential sales value.

Weaknesses

- Depended of heat from the CHP for dryer and thickener.

Opportunities

- Production of LBG (liquefied bio-methane)
- Dried product (granules) could be improved to fit more with the demand of the retail market.

Threats

- Legislation (regional) becoming more strict on N emissions and application.

3.1.3.4 Suggestions and advice provided in SYSTEMIC

In their continuous process of optimisation, Biogas Bree has been able to count on the SYSTEMIC consortium for support whenever required.

In 2018, the P and N content of the liquid fraction of the vegetal digestate was too high for profitable and easy marketing in the surroundings. Also, the large volume of vegetal digestate (43 ktonne per year) and the prospect of more stringent fertiliser application limits makes Biogas Bree think about their next move to be prepared for the future.

An ideal nutrient ratio that they could apply on the surrounding land would be 3N/1 P_2O_5/4.5K. It would be very much wanted by regional farmers for grass or maize in the area and would therefore have a low transport cost.

Reducing the P content of the LF of the vegetal digestate

To reach this, the P_2O_5 content from their vegetal liquid fraction should be lowered from 1.5 - 2 g P_2O_5/kg to 0.5 - 1 g P_2O_5/kg. By achieving this, they would be able to apply the same volume of liquid fraction in the area on half the amount of land.

The vegetal feedstock has a high biogas potential (f.e. molasse), but on the downside, it renders the digestate very sticky and viscous. This contributes to a suboptimal separation of the digestate by the centrifuge (only 40% P-removal to the solid fraction) at a high cost due to polymer use and maintenance.

Addition of fibre-rich feedstocks

SYSTEMIC brought them in contact with Waterleau NewEnergy, who advised them to mix more fibre-rich (but less energy rich) feedstocks in the vegetal diet of the digester. This could help with the viscosity problem and hereby improve the (phosphorus) separation efficiency. However, Biogas Bree didn't want to adjust the high energy diet of vegetal digester and therefore chose to focus on improving the separation efficiency by means of different flocculants and coagulants.

Optimization of additive use

Together with many different consultants and product suppliers they have been performing tests, which at lab scale always proved to be successful. However, on full scale, they did not bring any significant improvement. The separation of the centrifuge seemed to have reached its maximum efficiency for their current substrate diet of the vegetal digester and hereby the vegetal digestate.

Thermophilic post-digestion

A trial with a thermophilic post-digester has been done in 2019, to maximise the biogas yield and eventually produce a liquid fraction after separation with a reduced DM content. The pilot test showed a 1% lower dry matter content in the LF than without thermophilic post-digestion. However, it would be too difficult to get the digesters in wintertime on a thermophilic regime and Biogas Bree was a bit reluctant to work with this unfamiliar different bacteria consortium and the risks it they thought it might have (e.g. foam production, less gas production or less stable?).

Lowering the water content and volume of the LF of vegetal digestate

The nutrient content of the liquid fraction of the vegetal digestate was already close to 3N/1 P_2O_5/4.5K. Lowering the volume with at least 40% would also increase the nutrient content to 10.8N/3.3 P_2O_5/9K (g/kg). The nutrient ratio is remains the same, but the phosphorus levels could be making marketing in Flanders difficult, due to strict P application limits. On the other hand, the lower volume would improve the storage and transport cost for this product and might create other profitable marketing options (e.g. go to further demand regions or offer more money to local farmers to use it).

However, this would require concentrating the liquid fraction of the vegetal digestate with a factor 1.6. This implies that concentrating options (i.e. drying of the concentrate) should also be further investigated.

Different technologies are possible for this (evaporation, membrane technology, N stripping-scrubbing) , but they would all need to be researched and tested if they could technically and economically produce the foreseen end products.

Microfiltration + reverse osmosis + ion exchange

Membrane filtration (microfiltration + RO + IE) was not an option for Biogas Bree to investigate: it was doubtful if microfiltration would be able to produce a clean input stream for the reverse osmosis unit (preferably below 1.5 or even 1 % DM) from their liquid fraction of vegetal digestate (8% DM) (see also NUTRICAS simulation ANNEX I.3.1 Centrifuge + microfiltration + reverse osmosis + ion exchange

”). As described above, the DM separation efficiency of the centrifuge was already at its maximum capacity and could not be increased more, to produce a LF with a lower DM content (as low as 3-4%) necessary as input of the microfiltration.

Acidification + vacuum evaporation

From Waterleau NewEnergy, Biogas Bree has heard about the difficulties to market or dispose the ammonia-rich evaporator condensate (i.e. condensed ammonium water) and therefore they want to look more into evaporation with prior acidification.

Evaporation could provide a more robust, less expensive and easier system to operate compared to extensive separation and membrane filtration. However, this would also mean that Biogas Bree would have to use more heat from the CHP for the evaporator and less for the dryer.

With an evaporation system, Biogas Bree estimated a 50% water evaporation from 37 ktonne liquid fraction per year, which would produce 20.3 ktonne concentrate of 6.4N/3.7 P_2O_5/9.9K (g/kg), a volume reduction of 45% (see also NUTRICAS simulation ANNEX 0).

To give Biogas Bree more practical information, the technical specifications and price estimation on different types of evaporators, SYSTEMIC facilitated site visits to Demo Plants Am-Power and Waterleau NewEnergy and Associated Plant IVVO.

Eventually Biogas Bree has gotten price offers from four different companies providing evaporation technologies, all providing different systems and configurations (i.e. single or multi-step, vacuum atmospheric, extra pre-and post-treatments). As mentioned before, Biogas Bree needed an evaporator with low heat consumption, yet a multi-step evaporator proved to be too expensive to be profitable in their business case. Also, after some pilot tests it became clear that foaming kept occurring above 55°C and that the amount of antifoam needed to reduce this was drastically increasing the OPEX (see also NUTRICAS simulation ANNEX 0). If the evaporator temperature is limited to 55°C because of foaming, the water evaporation rate would be too low to be profitable; i.e. not possible to produce a concentrate of 20-30% DM.

Phosphorus recovery by means of RePeat technology cascade

In Flanders, depending on the soil phosphorus status, P is frequently the first limiting nutrient when applying organic fertilisers to the soil. The RePeat cascade, developed at Demo Plant Groot Zevert, could therefore be interesting for their case. The simulation was not performed, because Biogas Bree wanted to keep the P in their dried product. Today they still have a profitable market for this organic fertiliser in pellet form across the border. Also, the use of more chemicals (acid and base) didn’t fit well with their beliefs of sustainability, safety and financial feasibility. If the context changes regarding regulation and market, it could potentially be reconsidered.

Optimization of combination air scrubber (acid and biological)

Biogas Bree has an combi air scrubbing system to scrub nitrogen from the exhaust gasses from the thickener and dryer. It is the concept of nitrogen scrubbing with sulphuric acid (H_2SO_4) and a second step where bacteria transfer ammonium (NH_4^+) to nitrate (NO_3) by nitrification in the presence of oxygen. Ultimately, this type of air scrubbers at Biogas Bree could produce clean air and an ammonium sulphate solution (>70 g NH_4-N/kg and 80 g S/kg, pH 5.5). This AS is a good alternative for calcium ammonium nitrate (CAN) and urea as supplementary fertiliser for maize because of the large amount or readily available nitrogen. Additionally, the sulphur is a very valuable nutrient when fertilising grass, which has a relatively high sulphur need of 75 à 100 kg N/ha/year (VLACO 2020).

In Flanders, ammonium sulphate produced by acid air scrubbing can be applied above the application limit of 170 kg N /ha/year. Additionally, it is much cheaper for farmers compared to CAN (estimated 25€/ha, including spreading costs (VCM 2020), yet they are still reluctant to use this product as alternative fertiliser. This is mainly because of the low pH, which can cause leaf burning when applied under the wrong weather conditions or with the wrong application technique (VLACO 2020; SYSTEMIC fact sheet Ammonium suphate for farmers[7]).

Therefore, Biogas Bree has been successfully optimising their N air scrubber to produce an AS of 9% N and a pH of 7. They achieved this by spraying scrubber water of pH 5.5, recycled from the acid scrubbing step over the NH_3 loaded air in the first step. This way NH_3 has more time to dissolve in the AS where it can optimally use all unreacted sulphate (SO_4-) in solution, creating an AS with higher pH (7) and higher AS concentration (38-40% $(NH_4)_2SO_4$.

In the framework of the UNIR project[8], Biogas Bree has also been testing methods to purify the ammonium sulphate solution to make it easier to use for farmers. For large amounts, sedimentation had proven most technically and cost efficient.

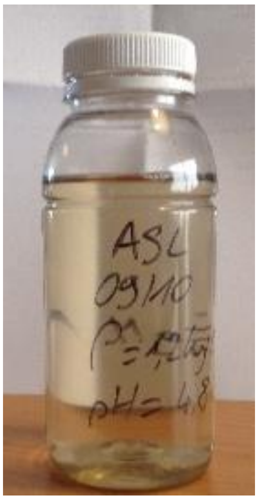

Figure 3-4 Purified ammonium sulphate solution from Biogas Bree.

New dryer and blending of products

To increase the drying capacity, a fluidised bed dryer was implemented instead of the belt dryer in 2020 to be able to blend their four liquid end products into a custom-made, dried and granulated digestate product.

This dryer was specifically chosen to create an end product that is dust free and by means of sieves a small round granule can be produced. Over the past year, Biogas Bree has been experimenting with blending in AS to increase the N and S content of the pellets, which could give them a higher sale values as "organic fertiliser". Tests have been not successful yet, creating dust in the fluidised bed dryer and unstable granules. Also, performing the tests in the dryer has proven to be costly, because each test puts the dryer out of its regular operation for a few days. Also, the first trials of the N + S enriched granules smell bad, which is a disadvantage when trying to enter the retail market for consumers with this product.

An important change would be needed if Biogas Bree decided to invest in producing bio-methane or liquefied bio-methane (LBG) (see 3.1.3.6 Future plans), because this would cause them to have no CHP residual heat or green electricity available for their current digestate treatment cascade (e.g. dryer, thickener) or most other nutrient recovery and reuse technologies. They would therefore have to get this energy elsewhere, which might be less sustainable, have right technology readiness level (TRL) or would not be economically feasible (for example solar panels, CHP on natural gas) and would require a complete redesign of the marketing plan for the produced end products.

[7] https://systemicproject.eu/wp-content/uploads/Systemic-AS-Product-V04.pdf

[8] https://www.vlaco.be/kenniscentrum/onderzoeksprojecten/unir

3.1.3.5 Impact of SYSTEMIC

Biogas Bree has been very actively involved in the SYSTEMIC project during all Living Lab meetings etc. and has always been openly communicating with the SYSTEMIC consortium and other SYSTEMIC biogas plants.

They have been a forerunner in testing and developing nutrient recovery and reuse technologies for their specific case.

Specific advice and support was provided by SYSTEMIC on ammonium sulphate in Flanders, technologies and suppliers of evaporation systems, crystallization of AS, new Nuclear Magnetic Resonance (NMR) sensors to measure the composition of digestate products for more optimal blending, and marketing the granules, etc.

By providing this, the SYSTEMIC consortium was happy to have made even a small contribution to what Biogas Bree has achieved in the past 4.5 years.

3.1.3.6 Future plans

Regarding biogas, Biogas Bree is exploring the possibility to produce bio-LNG (liquefied bio-methane) as a fuel for transportation. This could be a very profitable choice, however it would require them to stop converting biogas into heat and electricity with their CHPs. Hereby, they would need to look for alternative (green and) affordable heat and electricity sources to keep their digestate treatment cascade running (i.e. dryer and thickener).

Next to improving the marketing of ammonium sulphate solution as alternative fertiliser, Biogas Bree is also following up the developments around technologies to crystallise ammonium sulphate and selling this it to the fertiliser industry, though this is technically still a challenge.

As a side project, André would like to further focus on getting their digestate granules to higher profit niche markets like garden centres and retailers. For this, still some work has to be done regarding an optimisation of the nutrient concentrations (N, S and K), smell issues and a good branding and marketing strategy.

In 2021, the "animal related digester" has been digesting ±9 ktonne per year, from which 5 ktonne were pig manure. In 2022, Biogas Bree will not be using animal manure anymore in the "Animal related digester" because then they would have to implement expensive flow meters on this digester, and the relatively low biogas production from the manure in this digester does not outbalance this cost.

3.1.4 Waternet – Waste water treatment plant Amsterdam-West (Netherlands)

3.1.4.1 Description of the company

Wastewater Treatment Plant Amsterdam West (Waternet) is the second largest wastewater treatment (WWT) plant of the Netherlands. It is treating the waste water of more than 1 million inhabitants of Amsterdam with an active sludge system, i.e. nitrification- denitrification and enhanced biological phosphorus removal (EBPR), a modified process by the University of Cape Town (MUCT).

EBPR exploits the potential of some micro-organisms, known as Phosphate Accumulating Organisms (PAOs), to accumulate phosphate (as intracellular polyphosphate). Activated sludge from the wastewater treatment process is anaerobically digestated.

3.1.4.2 Business environment

The digestate from wastewater treatment sludge contains a lot of nutrients and organic matter but also heavy metals, hormonally active substances, persistent organic pollutants, etc. In the Dutch legislation it is therefore considered as “waste” and has to be incinerated.

Spreading regulation

Application on soil is only possible if it meets the standards of the ”BOOM-B” regulation. The heavy metal levels of the regulation are so strict that most of the sewage sludge produced in the Netherlands does not meet that standard and is incinerated. Phosphorus and other nutrients in the remaining ashes are presently not recovery nor reused.

In other EU countries (f.e. France) sludge does not have a waste-status and can be used in agriculture. Yet, the restrictions on the transport of “waste” outside of the Netherlands prevents this.

Extraction on the valuable components (macro-nutrients, water, organic matter) and using them in local agriculture is still prevented by legislation.

Phosphorus limits

For recovered struvite there are more possibilities:

- The EU Fertilising product regulation (FPR) EC 2019/1009 includes end-of-waste criteria for STRUBIAS (i.e. conditions for free trade in European Union);
- After incorporation in FPR, expected to be also allowed in organic farming;
- Fertiliser producer ICL Fertilizers is located less than 10 km from WWTP Amsterdam West, and accepts recovered struvite as secondary resource for the production of mineral phosphorus fertilisers.

Nitrogen limits

Recovered ammonium salts (stripping-scrubbing or acid air scrubbing), are assumed to be free from heavy metals and other contaminants and can be used in agriculture.

Nutrient demand

The closest marketing route for recovered phosphorus is ICL Fertilizers, but use in Germany as fertiliser is also possible. Recovered nitrogen as ammonium sulphate solution (from acid air washing) can be used as a N-fertiliser in agriculture in the Netherlands. However, it only needed in spring in a small time frame (three months). This prevents a valuable business case for recovered nitrogen as a fertiliser in the present market. Also, for the case of Waternet, recovery of nitrogen from digestate is not technical and economically favourable (see 3.1.4.4 Suggestion done in SYSTEMIC and BDP).

3.1.4.3 Business case evolution during SYSTEMIC

Feedstocks

Anaerobic digesters (34,400 m³) are located on site to mesophilically digest primary sludge from the primary sedimentation and activated sludge from the biological waste water treatment.

Table 3-11 Origin of feedstock at Waternet (Amsterdam-West), the Netherlands

Type	Mass /year (ktonne/year)	
	2018	2019 – 2020 – 2021 (estimation)
Primary sludge	300	310
Waste water treatment sludge	300	300
Total	600	610

Biogas production

In 2018, 13 million cubic meter of biogas is produced and valorised in the CHP (4 MW el) of the nearby household waste incineration installation. About 20,000 MWh of the produced electricity is used per year in the WWTP and digestate treatment process and the rest of the electricity goes to the grid.

There is an exchange of residual heat with the nearby municipal solid waste incineration company. Therefore, Waternet uses the amount of heat that is required, which is 50,000 GJ thermal energy for heating of the digesters.

In March 2021, Waternet implemented a biogas upgrading installation for the total biogas production.

The capacity of the installation is 14.7 million m^3 biogas per year. The biogas is separated in biomethane and CO_2 through membranes. The biomethane is fed into nearby natural gas grid.

The CO_2 from the biogas will be liquified and can used by greenhouse farming (OCAP pipeline), cooling trucks and acidification of drinking water.

Digestate treatment cascade

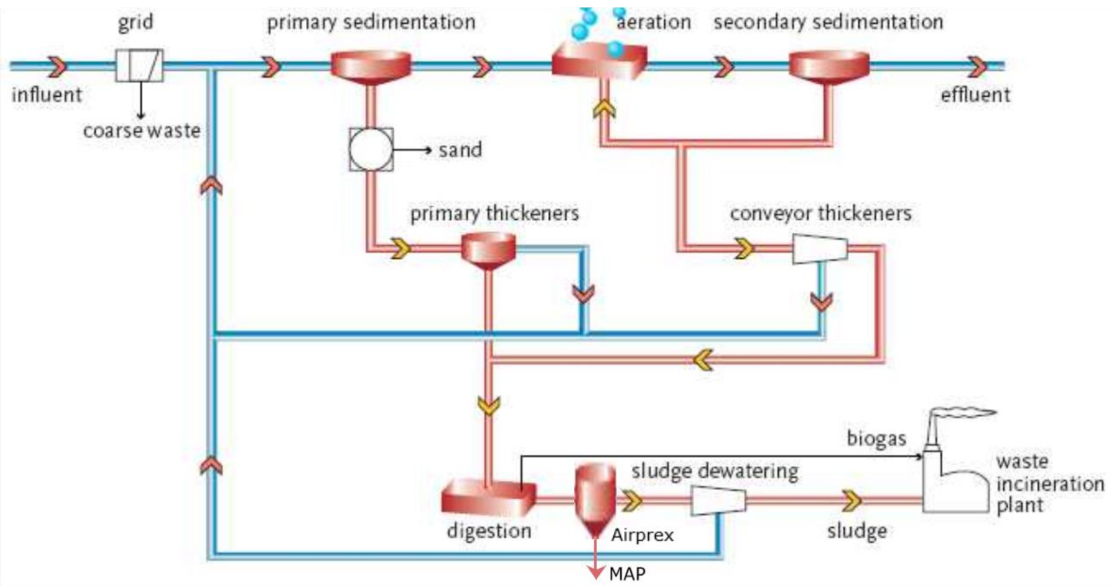

Figure 3-5 Scheme of the WWT process and anaerobic digestion and digestate treatment at Waternet-Amsterdam-West.

Waternet installed and struvite precipitation reactor (Airprex ®) on the digested sludge, before the de-watering step with a centrifuge. The main reason was struvite precipitation (scaling) in pipelines and on the dewatering equipment which caused wear and tear on the centrifuge. A massive build-up of struvite crystals ($MgNH_4PO_4.6\ H_2O$ (N-P-K, 5-28-0)) in the sludge holding tank was discovered. Two important factors were causing this struvite deposition.

The phosphorus captured in the biomass of the bacteria is released during anaerobic digestion and reacts with the present ammonium: Mg^{2+} + NH_4^++PO_4^{3+} + $6H_2O$ → $MgNH_4PO_4.6H_2O$ (mono-ammonium-phosphate or struvite)

- The design of the digester, where sludge falls from 20 meters high and with piping that includes angles of 90°, creates a CO_2 stripping through turbulence. This stripping induces a pH rise, which favored the formation of struvite crystals, pushing the equilibrium to the right, even though there is no optimal molar Mg:P ratio (Waternet: 0.22; ideal for struvite crystallization: 1:1).

By implementing a struvite reactor controlled precipitation can be obtained, under the addition of magnesium base (Mg^{2+}).

Because phosphate binds extra water to the digestate, and by removing this the dewaterability of the resulting digestate was improved with 3% (DM content increase).

Because struvite has a density of 1.7 g/cm³, it is relatively easy to separate, however only 50% of the formed struvite could be extracted. The remaining struvite stays in the digested sludge. The struvite still needs to be cleaned to remove digestate residues.

Currently, the AirPrex® system can remove 95% of the ortho-phosphate from the digestate as struvite, which is 20% of the total phosphorus content of the digestate.

This with adding a molar ratio of 1.8 - 2.2 for magnesium:phosphorus to the digested sludge before AirPrex (Muys et al. 2021; Veltman 2012).

Table 3-12 Composition of the end products at Waternet (2018 – 2019 – 2020 – 2021, estimation), including nitrogen (N), phosphorus (P) and potassium (K)

Input		Digestate		Low-P digestate	
After		Airprex		Centrifuge	
Product	**Digestate**	**Struvite**	**Low-P digestate**	**Solid fraction**	**Liquid fraction**
Mass (ktonne/year)	650	0.5	650	90-100	0.3 (recirculation to WWT)
Dry matter (%)	3.6	90	3.5	23.5	0.4
Organic matter (g/kg FM)	244	77	2.5		
N total (g N/kg)	1.8	50	1.75	50	1,000 mg/l
NH_4-N (g N/kg)	0.6		0.81		
P total (g P/kg)	1.5	126	1.4	40	40 mg/l
ortho-P (g P/kg)	0.22				
K total (g K/kg)	0.38		0.44		

Labour

The anaerobic digestion and digestate processing line is operated by 2.5 full time equivalents.

Destination of the end products

At Waternet, struvite is recovered from the digestate and this is sold to ICL Fertilizers Europe (50 - 100€/tonne), who uses it as as secondary raw material for phosphorus fertilisers and sometimes blends it directly in the fertiliser when needed.

The solid fraction is incinerated together with household waste in the nearby waste incineration plant at a cost of € 85 per tonne. The liquid fraction is recirculated to the waste water treatment process.

SWOT analysis of Waternet

Strengths

- Large amounts of digestate provide economic scale advantage for digestate processing technologies.
- Biological phosphorus recovery in WWT increases P in the digestate.
- 10+ years of in-house know-how and experience with struvite precipitation system.

Weaknesses

- Sludge needs to be incinerated under present regulation.
- Struvite precipitation requires the addition of magnesium base (Mg^{2+}), which is at the basis also a non-renewable element.

Opportunities

- Extraction of struvite as recovered P fertiliser.

Threats

- High costs (for chemicals).

3.1.4.4 Suggestion done in SYSTEMIC and BDP

The financial benefits for installation of the struvite precipitation unit (Airprex) in 2013 have proven to save 450,000 €/year (Veltman 2012) because of reduced maintenance in the digestate dewatering: no more struvite precipitation in the equipment and pipes and higher dry matter content of the solid fraction with 20% less polymer use. This increases to 475,000 € when the sales price of struvite to ICL (500 tonne struvite/year x 50€/tonne = 25,000€) would be taken into account.

Currently only 20% of the total phosphorus present in the digestate can be recovered as struvite. Waternet would like to explore how to increase this amount of recovered phosphorus. Moreover, they intend to dry sludge with residual heat of the digester and to use it as a fuel for e.g. cement industry. For this latter purpose, a low P content is desired as it increases the economic value of the sludge as a fuel.

As such, a simulation was performed in the NUTRICAS Tool of the first acidification step (acidification) of the RePeat cascade (developed by Demo Plant Groot Zevert Vergisting) to release more ortho-phosphate in the liquid to obtain an increased P recovery as struvite. In this theoretical scenario for 650 ktonne of digestate per year, only the effect on the cost for chemicals and revenues from struvite were taken into account (ANNEX I.4.1 RePeat-acidification step on digestate”). This simulation also did not take into account any additional benefits from an even more improved dewaterability of the digestate, which could also reduce the transport and disposal costs further.

It could be concluded from the simulation that even though more phosphorus would be released and recovered as struvite, the revenues did not balance the enormous amount of chemical costs required to produce this struvite.

Using cheaper (recycled) H_2SO_4 could lower the chemical cost for this acid, however this also can have more impurities and contaminants, which could influence the struvite quality. Looking at biological ways to acidify the digestate, for example by using sludge from the hydrolysis step to produce struvite, might also be a cheaper option to transfer organic phosphorus to soluble ortho-P.

A higher price for struvite could also increase the revenues. This might be found in the niche market of organic farming, if struvite would be included Annex I of Regulation (EC) No 889/2008) when the STRUBIAS ANNEX is implemented in the Fertilising Products Regulation (2019/2009) and this enters into force in 26 June 2022.

Recovery of nitrogen from the digestate was not desirable, because the ammonium (NH_4-N) is needed to produce struvite and can be easily and removed at a low costs in the WWT.

3.1.4.5 Impact of SYSTEMIC

Since Waternet has a lot of internal technical know-how, a very specific business case, including enormous amounts of municipal WWT sludge digestate and a specific digestate treatment (i.e. struvite precipitation) which was not included in any of the SYSTEMIC demo plants, providing dedicated advice to Waternet on nutrient recovery and reuse was not always easy for the SYSTEMIC consortium.

However, during the SYSTEMIC project Waternet has been involved in research work and project by SYSTEMIC partner Wageningen University & Research (Regelink et al. 2017) and have actively attended the SYTEMIC Living Lab meetings. The first Living Lab meeting in 2018 was even hosted at Waternet.

The reason they kept attending all SYSTEMIC meetings was because they found the networking and experience exchange with other biogas plants and consortium priceless and unique opportunity.

3.1.4.6 Future plans

In the past years, Waternet has been evaluating the different options for valorisation of the sludge digestate and nutrients and came up with the following solutions: end 2023 the solid fraction of the digestate will be dried to 90 % DM with residual heat from the nearby municipal solid waste incineration plant. The dried sludge will be mono-incinerated to produce heat and electricity. The remaining ashes will separately processed to extract the phosphorus from sewage sludge digestate ashes.

Using this design, a much lower volume of acid is needed to extract phosphorus from the lower mass of ashes compared to the initial amount of 650,000 tonne of raw digestate.

Waternet is also exploring a bio-coal system for their excess wastewater activated sludge due to the growth of Amsterdam.

For the biogas, Waternet will be producing 14.7 million m^3 biogas per year. They are planning to change biogas valorisation from CHP to upgrading to bio-methane. The biogas will be separated in biomethane and CO_2 through membranes. The biomethane is fed into the nearby natural gas grid, which will give also a more profitable business case.

The CO_2 from the biogas will be liquified and can used by greenhouse farming (OCAP pipeline), cooling trucks and acidification of drinking water.

3.1.5 GMB – BIR BV (Netherlands)

3.1.5.1 Description of the company

GMB is a company supplying services in design, construction, management maintenance and operation of waste solutions.

One of the six clusters of their organizational structure is GMB BioEnergy which includes their biogas plant in Lichtenvoorde named Biologische Industriële Reststoffenverwerking BV (BIR BV, in English "Biolgocial Industrial Residuals Processing"). BIR BV is a joint venture between Waterstromen BV in Lochem and GMB BioEnergie Zutphen BV.

At the site of BIR BV, there is also a waste water treatment (biological COD-removal, N-removal by Annamox-technology) treating wastewater from the neighbouring tannery industry.

3.1.5.2 Business environment

Since BIR BV takes in food and kitchen waste, grease from sewage and waste from food processing industry (slaughterhouses and egg processing), and pharmaceutical industry, the digestate contains a lot of nutrients and organic matter but also heavy metals. Because of the use of chemical and pharmaceutical feedstocks, the concentrations of copper and zinc exceed the limits for the use of digestate for agricultural purposes. According to the Dutch and European (waste) legislation digestate is therefore seen as waste. A status which cannot easily be changed.

In general, digestate of this origin can also contain hormonally active substances, persistent organic pollutants, etc. The partition and activity of these substances in digestate and derived products are not yet clear and the risks and effects when these products would be applied on land are still unknown. Additionally, there is still a high-risk perception of consumers. Extraction on the valuable components (macronutrients, water, organic matter) and using them in agriculture is also still prevented by legislation.

For these reasons, the only solution is to incinerate the digestate.

Nitrogen limits

If nitrogen from the digestate would be recovered as e.g. scrubber salts these would be allowed to be used according to the nitrogen application standards, depending on the crop grown.

However, only ammonium sulphate from air scrubbing can be traded fertiliser (ANNEX Aa form article 4 of Dutch fertiliser regulation).

Nutrient demand

In the province of Gelderland the most dominantly cultivated crops were in 2019: maize (56% of cultivated area (CA)), potatoes (10% of CA), winter wheat (8% of CA) and sugar beets (4%). All these crops could benefit from additional nitrogen fertilisers.

3.1.5.3 Business case evolution during SYSTEMIC

Feedstocks

The feedstocks are received in four buffer tanks, which can be heated in order to prevent freezing of the feedstock in winter.

Table 3-13 Origin of feedstock at GMB-BIR BV (2018-2019-2020-2021)

Type	Mass /year (ktonne/year)
Food waste from catering industry	12
Waste streams form chemical, pharmaceutical or food industry	28
Total	40

Biogas production

The mesophilic anaerobic digestion process produces yearly over 4-5 Mm³ of biogas which is valorised in a CHP to electricity and heat (±15,000 MWh). The electricity is used on the waste water treatment site (next to the biogas plant) and 78% goes to the grid.

Heat from the CHP is used to heat up the waste water for optimal biological treatment and to keep the digesters on temperature. The rest of the heat (approximately 21%) goes through an underground pipeline to the public swimming pool and town hall of Lichtenvoorde and plans are made to make the heat also available for other public buildings.

Heat from the composting process in Zutphen is used to heat up the composting tunnels and the buildings on site.

Digestate treatment cascade

GMB-BIR BV (Lichtenvoorde)

- In 2016, a belt press was installed to reduce the volume of the digestate (solid fraction).
    - The liquid fraction was treated in the waste water treatment on site.
    - The solid fraction of the digestate after the belt press is transported to GMB BioEnergie in Zutphen, 30km from Lichtenvoorde.

GMB BioEnergie (Zutphen)

- In Zutphen, they take in the digestate from BIR BV and other (liquid) sludges. These are mostly sludges from waste water treatment sludge or slaughterhouse sludge (which higher levels of copper and zinc). These sludges have a higher gate fee than for example flotation a sludge from dairy industry, mainly because of the heavy metal content. The mixture is dewatered by means of a decanter centrifuge.
- The liquid fraction from the decanter centrifuge is treated in a Dissolved Air Flotation (DAF) unit.
- By adding iron chloride solution, phosphorus is complexed and scraped off with suspended solids together with organically bound nitrogen.
- The liquid after the DAF still contains most ammonium (NH_4-N) and potassium.
- The solid fraction after the decanter centrifuge is mixed with wood chips and sent to the composting tunnels for bio-thermal drying, together with other dewatered sludge streams from communal waste water treatment.
- The air from the composting tunnels contains ca. 30% of the nitrogen present in the input streams. It is cleaned with acid air scrubbing, producing an ammonium sulphate solution (40% w/w).

GMB composting (Tiel)

- In the GMB composting plant in Tiel, only municipal waste water treatment sludge is composted.
- The composted product is called "bio-granulate".

Table 3-14 Estimated composition of the end products at GMB BioEnergie (2020), including nitrogen (N), phosphorus (P) and potassium (K).

	BIR BV	**GMB BioEnergie**					
Input		Digestate BIR BV + sludges		Solid fraction	Digestate + sludge	Liquid fraction	Air from composting process
After			Decanter centrifuge	Composting	Decanter centrifuge	Biological nitrification-denitrification	Acid air scrubbing
Product	**Digestate**	**Input mix**	**Solid fraction**	**Compost**	**Liquid fraction**	**Dischargeable water**	**AS solution**
Mass (kt/year)	21	237	41	11	196	196	2.2
Dry matter (%)	5-6	4-5	20-25	62	0.4		40
N total (g N/kg)	5		16	28	0.7		80
NH_4-N (g N/kg)							80
P total (g P/kg)	0.7		6	25			-
K total (g K/kg)				3			-
S (g S/kg)	1.3		3	10			90

Labour

For the dewatering of digestate and sludges there are 2 operators (FTE) necessary, for composting (196 ktonne) there are 10 operators (FTE) necessary.

Destination of the end products

GMB-BIR BV (Lichtenvoorde)

- The liquid fraction was treated in the waste water treatment on site at BIR BV and discharged.

GMB BioEnergie (Zutphen)

- The compost from Zutphen also contains industrial waste water sludges and digestates and is therefore also incinerated in several waste incineration plants in The Netherlands and Germany.
- The liquid after the DAF is treated with biological nitrification-denitrification, in the waste water treatment plant of Waterschap Rijn en Ijssel, next to GMB BioEnergie Zutphen.
- The DAF sludge is returned to the storage for sludges and is again dewatered with the centrifuge. Eventually it is also composted and incinerated.
- GMB is already using the produced ammonium sulphate from air scrubbing as a fertiliser in agriculture. It is sold to fertiliser traders who are selling it to farmers in the provinces of Groningen, Drenthe and Overijssel in the North of the Netherlands.
- GMB has been involved in a synergy with Groot Zevert Vergisting (Beltrum, NL), which produces mineral concentrate from digestate and mixes it with the GMB ammonium sulphate to increase the N content to form the "Green meadow fertiliser" tested in the Biobased Fertilisers Achterhoek pilot (2020-2021).

GMB composting (Tiel)

- In the GMB composting plant in Tiel, only municipal waste water treatment sludge is composted. A cooperation with their French partner Sède, GMB wanted to use the composted sludge on French agricultural land as nitrogen-phosphorus (NP) rich organo-mineral fertiliser ("Tradiphos").GMB and Sède investigated and confirmed that the use of Tradiphos was safe for the soil. Because it is a hygenised product, pathogens are removed. After going through an administrative request process of multiple years with the Dutch and French government, this bio-granulate (i.e. composted sludge, "Tradiphos)) was received a product status in France.
    - Thus, in the summer of 2019, the export of the first batches of Tradiphos to France started and fertilisation trials were started to see the effect on the crop yield. In 2019, they were able to sell over 4,200 tonnes of Tradiphos in Northern France, which translates to 186 tonnes of phosphate (P_2O_5). As an alternative for mineral fertilisers, Tradiphos could prevent the use of more than 1,000 tonnes of conventional superphosphate. The product was considered as a homogeneous and odourless soil improver, which is particularly suitable for maize, grain and beets.
    - However, to continue this export to France, GMB needed Tradiphos to have an End-of-Waste status from the Dutch government. The Dutch government declined this request in 2020 because of the possible risk of "substances of very high concern" (Dutch: Zeer Zorgwekkende Stoffen"). The export and use of Tradiphos in France was ceased immediately. Thus far, the bio-granulate goes back to incineration.

SWOT analysis GMB-BIR BV

Strengths

- Because of incineration there is no spreading of heavy metals and other substances of concern to agriculture.
- Experience with digestate dewater and composting since 2004.
- Recovery of energy from AD and composting of sludge and waste.

Weaknesses

- High cost.
- Internal transport costs (Zutphen – Lichtenvoorde).
- No stuctural NRR yet.
- Use of pharmaceuticals as input streams and high copper and zinc levels in the digestate makes disposal of products difficult (only incineration).

Opportunities

- More attention from policy makers to production of green energy and circular economy.
- There is space for expansion of the GMB BIR site (Lichtenvoorde).

Threats

- Possible presence of substances of high concern hinder use of recovered nutrients in agriculture.
- Permit procedures are long and insecure.
- Local community is reluctant for expansion of the plant.
- Technological risks of new technologies to recover and reuse nutrients.
- More AD plants being created, means extra competition.

3.1.5.4 Suggestion done in SYSTEMIC and BDP

Local treatment at BIR Lichtenvoorde, including drying of digestate and N-stripping-scrubbing and WWT of N-poor digestate could reduce transport costs to Zutphen.

Extraction of nitrogen (ammonia stripping-scrubbing) and phosphorus (P precipitation) could help to close the nutrient cycles. Scrubber salts have proven to be equally performing as mineral N fertilisers with heavy metal contents below the limit values for N fertilisers indicated in the EU Fertilising Products Regulation (EU/2019/1009) (Huygens et al. 2019).

A simulation with the NUTRICAS Tool was done for the scenario of **N stripping-scrubbing** from the digestate of GMB BIR BV (ANNEX I.5.1 Nitrogen stripping-scrubbing”). The simulation showed that 80% of the NH_4-N in the digestate could be recovered as ammonium sulphate (23% $(NH_4)_2SO_4$ solution).

The performance of an N stripping-scrubbing technology from Nijhuis Saur Industries on the GMB BIR digestate and liquid fraction was also investigated by waterboard Waterstromen in 2021. After N stripping-scrubbing the nitrogen content could be reduced to <1% N per kg DM. This is comparable to the NUTRICAS simulation (i.e. 0.8 NH_4-N/kg N stripped digestate). The decision about investing a such a technology will fall in the coming months[9].

The implementation of the RePeat cascade at GMB BIR could produce a calcium phosphate sludge and a low-P soil improver, like operational at Demo Plant Groot Zevert Vergisting. These biobased fertilisers could be warmly welcomed in agriculture in the Achterhoek region and Germany across the border. However, due to its origin including pharmaceutical waste, the original digestate and derived end product

[9] https://www.nieuweoogst.nl/nieuws/2021/08/03/afvalverwerker-werkt-aan-bodemverbeteraar-uit-restmateriaal

low-P soil improver would not be allowed to be used on agricultural land in the Netherlands and still needs to be incinerated. This scenario was therefore not further investigated.

3.1.5.5 Impact of SYSTEMIC

GMB has been involved as a SYSTEMIC Outreach Location from the start until the very end of the project. Thanks to SYSTEMIC they have been able to visit many different biogas plants with different digestate treatment cascades (WWT plant Amsterdam- Waternet, Am-Power, Groot Zevert Vergisting, BENAS, Waterleau NewEnergy). Here, they were able to make new contacts with other plant owners and technology providers (e.g. Nijhuis Industries) and exchange practice related experiences, gaining additional insight in do's and don'ts for nutrient recovery and reuse challenges and solutions.

3.1.5.6 Future plans

GMB-BIR BV (Lichtenvoorde)

There is still approximately 700 MWh of heat available at BIR BV, which GMB plans to provide to other public buildings, aside from the public swimming pool. The heat can also be used for a N stripping-scrubbing installation.

Because in the past two years the limits for nitrogen emissions are getting stricter (cfr. also in the surrounding countries), and biogas conversion in CHP emits too much nitrogen (i.e. NOx), BIR BV is exploring the transition to upgrading the biogas to bio-methane to feed in the existing gas grid. To make this economically sustainable, the treatment capacity will need to be extended to 100,000 tonnes per year (+150%).

The decision about investing a N-stripping-scrubbing will fall in the coming months (2021).

GMB BioEnergie (Zutphen)

At this moment, GMB thinks it is best to focus the treatment of the composted product from Zutphen on incineration, which will be currently the safest and most sustainable approach.

Therefore, they have made a long term contract with an new incineration plant in Delfzijl (EEW, 200 km from Zutphen) that 75% of their compost can be incinerated there. The composting process at Zutphen is mainly used to decrease the volume of the solid fraction and increase in calorific value before transportation to the incineration plant. In the near future ashes from the incineration plant will be used for P recovery.

GMB composting (Tiel)

After the failed test and elaborate research to get Tradiphos (from GMB Tiel) being used as a fertiliser in France, other options for this product are to treat the compost as biofuel in Germany or in lignite fired power plants. This way only the nitrogen via acid air scrubbing of the composting tunnels is recovered and the rest of the nutrients in the compost are not recovered nor reused.

3.2 New Biogas Plants to be built, designed with nutrient recovery

3.2.1 Atria – Nurmon Bioenergia Oy (Finland)

3.2.1.1 Description of the company

Atria is one of the leading meat and food production companies in Northern Europe with 20 production plants in four countries. Their headquarters are located in Finland.

3.2.1.2 Business environment

The region of the slaughterhouse and food factory in Seinäjoki (Finland), is characterised by an intensive agricultural production, on Finnish scale. In the province of Etelä-Pohjanmaa there are per year 2 million tonnes of animal manure available. The amount of manure will be stable or slightly increasing in the coming period.

Figure 3-6 Overview of different food production facilities of Atria in Scandinavia (Left); Food factory in Seinäjoki, Finland (right).

Spreading regulation

In Finland, the growing season is quite short. According to the legislation, all fertilisers (manure derived fertilisers, mineral fertilisers, etc.) cannot be spread on cropland between 1 November and 31 March and on snow covered, frozen and/or water saturated soils. This makes that spreading is only practically feasible and effective less than 2 months per year. The rest of the year, the produced digestate has to be stored, which requires a very large storing capacity.

Over 95 % of farmers are committed to the National legislation of environmental compensation for agriculture. It states limits for nitrogen and phosphorous spreading amounts/hectare depend on the crop type, yield, the characteristics of soil etc. In the future EU Common Agricultural Policy period, these limits will be transposed into national legislation.

Phosphorus limits

The phosphorus level in the soil determines the P application limit, which is based on the soil fertility class (i.e. P level in the soil, 7 classes) and type of crops that is cultivated (Table 5 in "Finish Food Authority 2020").

For cereals, oilseeds and legumes and forage grasses it ranges between 0 and 46 kg P/ha/year. However, if the P soil status is in class 'satisfactory' or 'High', there is a derogation for manure, where it can be applied above the stated limit (for example for cereals in soil class 'High' 15 kg P/ha/year instead of 5 kg P/ha/year). Also, for cereals, if there is an increase in achieved yield, more phosphorus can be added accordingly (Table 6 in "Finish Food Authority 2020"). These exemptions have been a continuous discussion point, because they stimulate potential over-fertilisation of these soils with P via manure application. In addition, it is possible to use P equalisation, with 5 years average value.

The P status of the soil (and thus the application limits) varies greatly in Finland and is in the in the Seinäjoki region is characterised by hotspot regions of animals and high P soils in places. Here, part of the produced manure needs to be transported to regions with lower P limits, approximately 50 km further.

Figure 3-7 shows that the amount of manure available in some municipalities is more than enough to supply for the crop P needs (i.e. 100%) and there is actually no need to supply additional mineral P fertiliser. This is even more obvious when the manure from fur animals are taken into account, which contains a lot of phosphorus (Figure 3-7, bottom figure). In Finland fur production is a significant sector.

Ilmajoki, Evijärvi, Jalasjärvi and Seinäjoki are examples of regions where the available P from manure is more or close to the amount of P that the crops need (Figure 3-7, top figure).

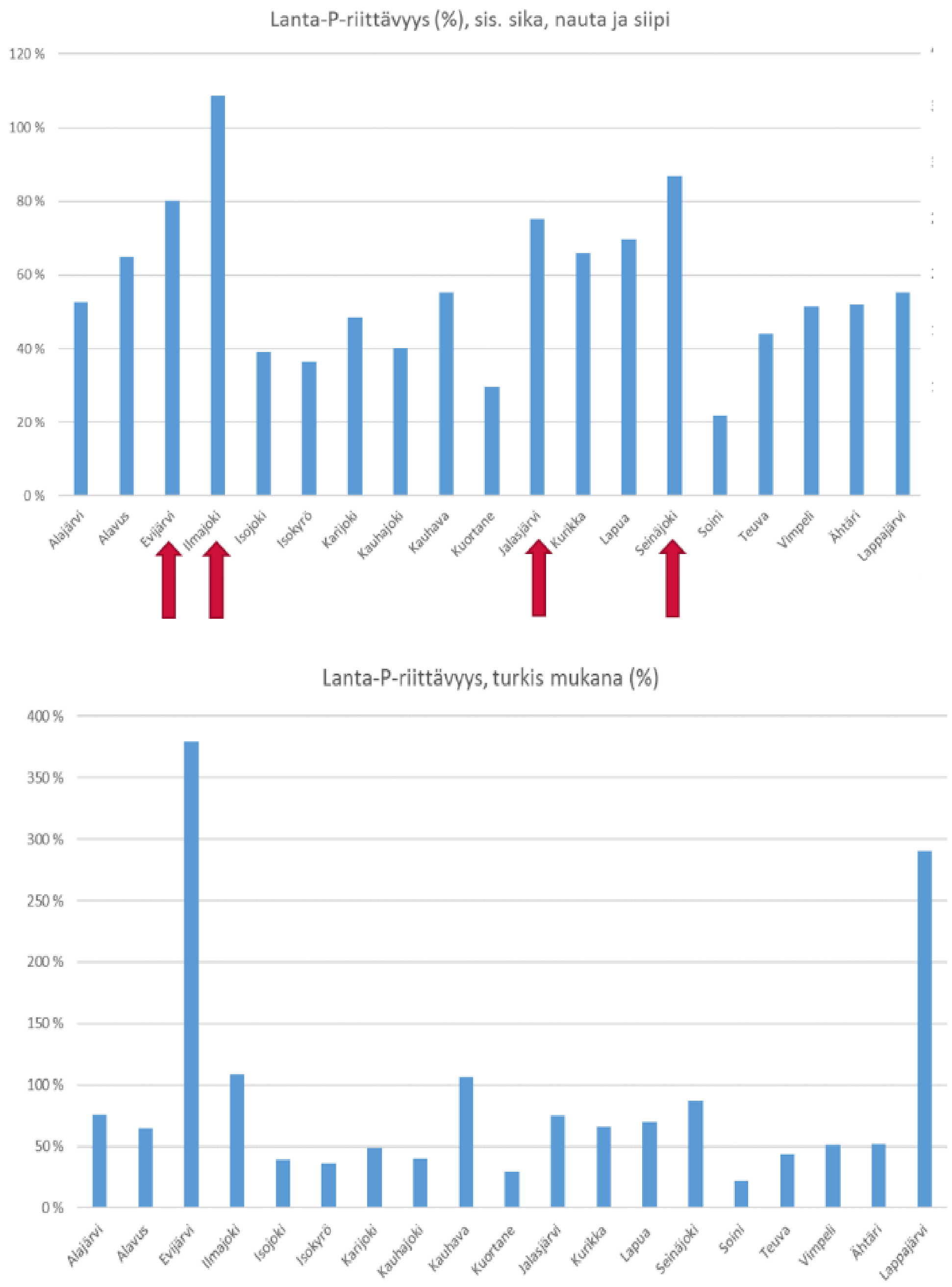

Figure 3-7 Percentage of available manure phosphorus (P) in different regions that is effectively used by crops. The top figure includes manure from cows, pigs and poultry. In the bottom figure also manure from fur animals is taken into account.

Nitrogen limits

The whole of Finland is designated as EU Nitrate Vulnerable Zone and there are no derogations (Figure 2-2). This means that manure and manure-based fertilisers can only be applied up to 170 kg N/ha/year (Nitrate Directive; 91/676/EEC). An organic fertiliser is classified as manure when it contains >10% of manure.

The soluble nitrogen limits in Finland depends again on the soil type, type of crops that is cultivated and the achieved yield level (table 1-3 in "Finish Food Authority 2020"). For increased yield levels, the additional nitrogen fertiliser can be added, but manure derived fertiliser never surpasses the limit of 170 kg N/ha/year.

Nutrient demand

The Atria food factory and slaughterhouse is located in agricultural area and the main crops are cereals (almost 60% of utilised agricultural area), grass (over 30%) and potatoes (over 2%). Pea and rapeseed/rape are each grown on under 2 % of utilised agricultural area. Maize and beets are not grown in the region, but perhaps in the future.

3.2.1.3 Business case evolution during SYSTEMIC

Atria recognised the biogas potential of the manure in the region and slaughterhouse waste from their meat processing factories and slaughterhouses in the regions Seinäjoki/Nurmo and Kauhajoki. (Figure 3-8).

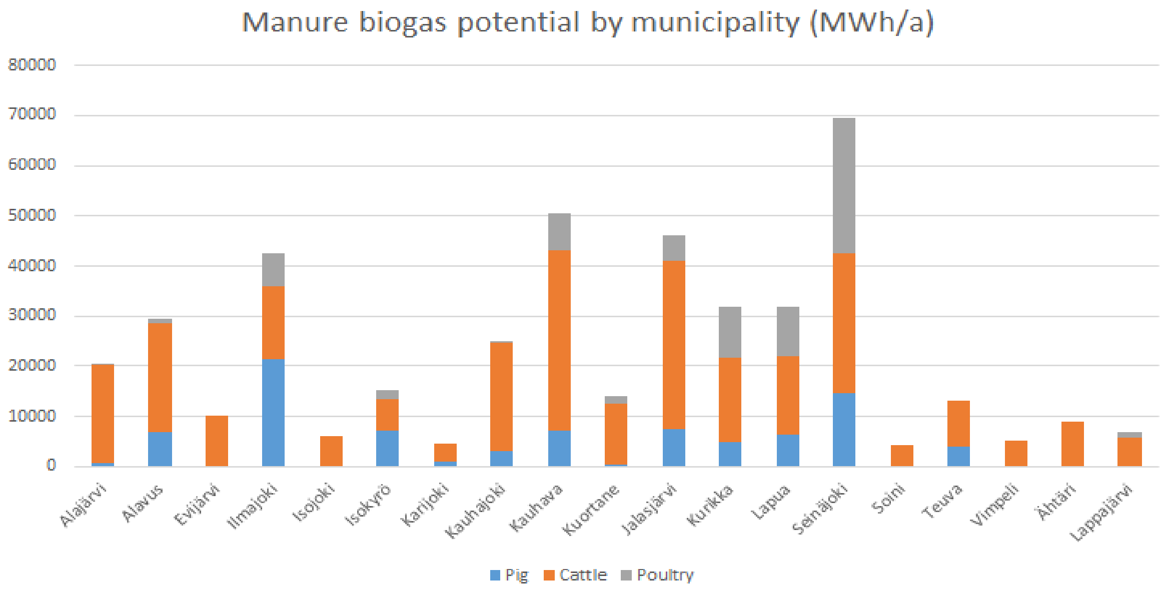

Figure 3-8 Biogas production potential from available pig, cattle and poultry manure in municipalities in Finland.

A biogas plant could be implemented at the logistically most optimal location (2 km from the food factory in Nurmo) and designed to not only produce liquefied biogas (LBG), but also treat the digestate to reduce the volume of the initial manure and hereby concentrating the nutrients. A reduction of the volume by means of evaporation technology seemed necessary, because otherwise storage capacity for 10 months a year had to be found for the raw digestate. If these recovered products could be further valorised, this could even further improve the business case.

A-Farmers is a part of Atria Group and has been responsible of the biogas project’s first steps. This subsidiary manages Atria’s primary production and all contracts with farmers and meat suppliers. They also help develop the farms and meat production sites, so they can work cost-efficiently and guarantee Atria's meat supply. During the SYSTEMIC project, Atria handed over the biogas project responsibility to Heikas Oy, remaining a minority shareholder itself. The biogas company name is Nurmon Bioenergia Oy.

During the SYSTEMIC project, the business plan for the new plant has been struggling with environmental permits, which have been ultimately approved. A very important factor in the business plan was the LBG price, which dropped (as like the prices of oil and natural gas) near zero when the Covid-19 crises began. Also there were prospects to some changes in support schemes (i.e. biogas blending and distribution obligation system, which affects taxation as well) and new subsidies from the Finish Government for manure based biogas production, and part of these remain still unclear. All these open issues changed the whole business plan and made the investment environment quite unclear. However, now in November 2021, the distribution obligation is clarified, and draft of new taxation system is available, and the biogas company believes that the project planning phase will be finalised in the coming months and that construction of the plant will start in 2022. They have already begun site preparation by removing the stands.

Feedstocks

In the start-up phase, the co-digestion plant will treat about 164 ktonne of feedstock per year out of which 70% is manure (i.e. pig, cattle, poultry). Co-substrates include slaughterhouse waste and food industry waste (Table 3-15).). After the start off phase, the capacity will be extended to 240 ktonne per year and probably later even to 360 ktonne per year.

Table 3-15 Origin of feedstock at Nurmon Bioenergia (estimation for when the plant will be operational)

Type	Mass (ktonne /year)
Pig slurry	90
Solid fraction of pig slurry	10
Cow manure (slurry)	60
Cow manure (farmyard)	25
Solid fraction of cow manure	3.7
Chicken manure	10
By-products slaughterhouse	25
Food industry waste	8
By-products milk processing	2
Plant biomass - silage or pressed solid fraction of silage	20
Total	253.7

To select the optimal location for the biogas plant, A-farmers has made an overview of the manure availability in the different municipalities in the region (Figure 3-9). The scale from red to green flags show if a municipality has more or less manure available compared to the crop's needs.

Negotiations with farmers were already started to establish contracts to supply Nurmon Bioenergia with the 240,000 ktonne of manure feedstock per year and these contracts will be finalised after the final investment decision. Each contract will be tailor-made to the farmer's needs (e.g. only supply manure, take back digestate derived products, etc.) and only 20% will eventually be simple, oral agreements.

Nurmon Bioenergia receives no gate-fee for the manure they receive. The selling point of the digestate-derived products is that they will have more readily available nutrients compared to raw manure and still supply organic matter, compared to inorganic fertiliser. If needed, Nurmon Bioenergia will also provide contractors with latest equipment for fertiliser application on the fields.

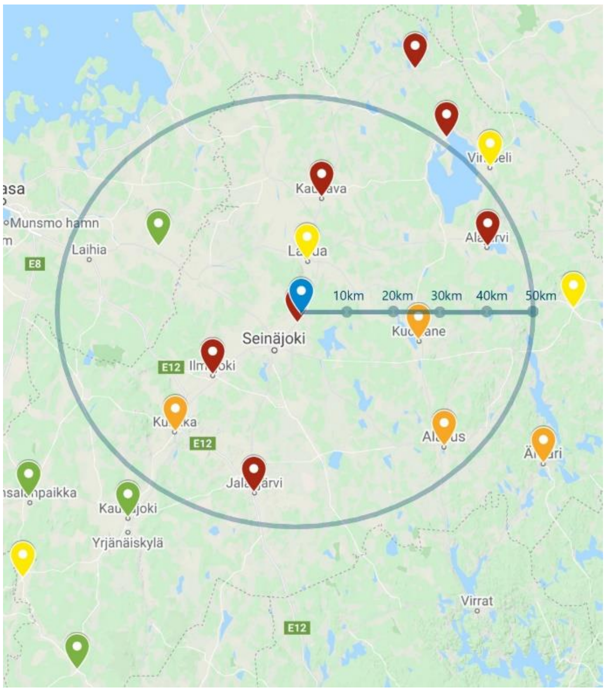

Figure 3-9 Manure availability in a 50 km radius around the biogas plant.

Biogas production

The biogas plant will include > 16,000 m³ reactor volume of mesophilic digesters. The biogas produced will be around 15 million Nm³/year. The biogas will be upgraded and liquified into 7,000 tonne of liquefied bio-methane (LBG) per year, which will be used as fuel for heavy traffic. Next to transport, part of it will be sold for industrial use (replacing e.g. oil or LPG). The energetic value of the LBG produced corresponds with 100 GWh, which could replace 10 million litres of diesel.

Digestate treatment cascade

The plant would be processing ca. 240 ktonne of digestate per year in continuous operation.

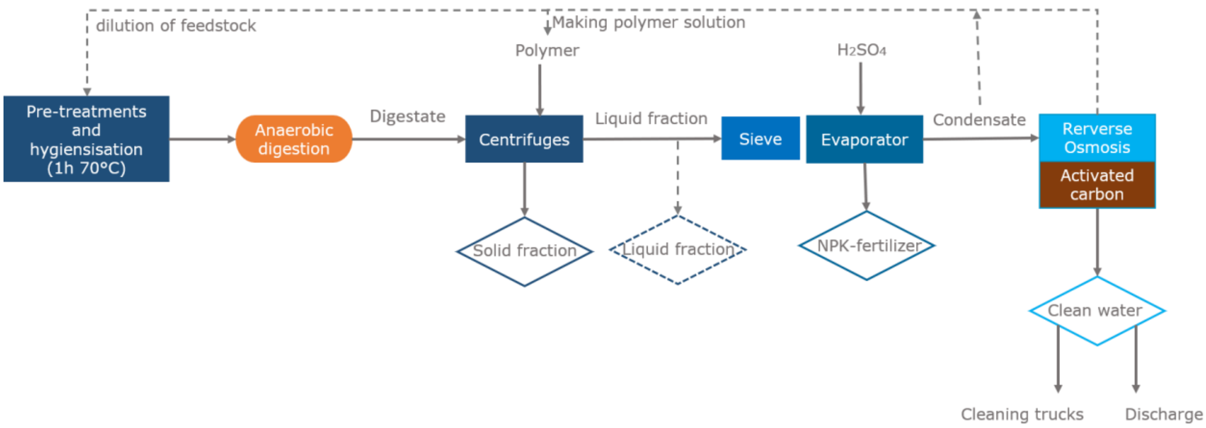

Figure 3-10 Scheme of the digestate treatment process with nutrient and water recovery at the Nurmon Bioenergia biogas plant.

- Feedstocks are received into a continuously mixed tank and diluted into 12% DM with recycled water if needed.
- After the receiving tank, mixed feedstock is directed into a pre-digester/hydrolysation tank before pumping through hygienisation into the mesophilic digesters.

- Digestate (8% dry matter, DM) is sent to a centrifuge for solid-liquid separation. Coagulation and flocculation are enhanced by the addition of polymer which is prepared with recovered water from the RO and condensate from the evaporator.
- The solid fraction contains ~85% of the initial total phosphorous (P) of the feedstock.
- The liquid fraction is directed through a step screening unit to evaporation. The screen will purify rests of animal hairs, straw, fouling particles etc. to achieve a DM content <2% before it is sent to the evaporation unit. The liquid fraction before the evaporator is acidified (with H_2SO_4) to pH 6 - 6.5 to maintain nitrogen in a NPK-concentrate produced by evaporation unit.
- The evaporator is assumed to be under maintenance three weeks per year. During that time, 10,600 tonne liquid fraction is produced, which will be used on land as a fertiliser or stored.
- To the produced condensate a small amount of base (NaOH) may be added to adjust the pH before going to the RO. This will ensure a balance between retaining most soluble organic acids (biological oxygen demand, BOD) and ammonia (NH_3) before discharging on waters.

Table 3-16 Estimated composition of the end products that will be produced at Atria – Nurmon Bioenergia Oy, including nitrogen (N), phosphorus (P) and potassium (K).

Input		Digestate		Liquid fraction		RO + active carbon
After		Decanter centrifuge		Evaporator		Condensate
Product	**Digestate**	**Liquid fraction**	**Solid faction**	**Concentrate**	**Condensate**	**Permeate**
Mass (kton/year)	230	185 + 10.6	43	30.5	143.8	100.7
Dry matter (%)	8.4	3.6	29	21		0.02
N total (g N/kg)	6.79	5.45	12.5	32.98	0.2	0.015
NH_4-N (g N/kg)	5.19	4.91	6.4	29.68	0.2	0.015
P total (g P/kg)	2.16	0.40	9.65	2.42	-	-
K total (g K/kg)	5.13	5.38	4.1	32.65	-	-

Labour

The biogas plant, including the nutrient recovery cascade is planned to be operated by for four operators working two shift per day of max. 10-11 hours/day. The staff will receive a training on operation of the nutrient recovery and reuse cascade based on previous experience, trial and error.

Energy

Since all the biogas is upgraded to LBG, no heat will be produced by a CHP unit. The whole digestate treatment cascade is designed to consume less heat (e.g. specific evaporator technology) and the required energy is provided by burning wood chips and buying renewable electricity from the net.

Destination of the end products

To be sure of the disposal of the produced digestate derived products, Nurmon Bioenergia conducted interviews with farmers in the region to estimate the amount of products they would like to receive. Based on this survey, it is estimated that recovered nutrient products can potentially fill in the demand of arable farms within a 40 km radius (Figure 3-11) corresponding 87,940 tonne of products (solid fraction and NPK concentrate) on ~ 20,000 hectares land.

Tailor-made contracts are set up with the farmers to ensure that the amount of feedstock is supplied to the biogas plant and the end products are sold, transported and applied as fertilisers on (their) land.

The solid fraction is stored at the plant for 1 – 2 months before transport to end-users which use it as such in agriculture as a fertilising soil conditioner. Available storage capacity has to be approved by the authorities to ensure that no dumping of end products will occur. For the feedstocks (i.e. manure), Nurmon Bioenergia can make contracts for the use of the storage capacity of the individual farmers if necessary.

The liquid fraction that is produced during 3 weeks maintenance of the evaporator will be used on land as a fertiliser or stored.

The condensate from the evaporator and the concentrate after the RO have low nutrient contents and they will be used for polymer manufacturing or feedstock dilution.

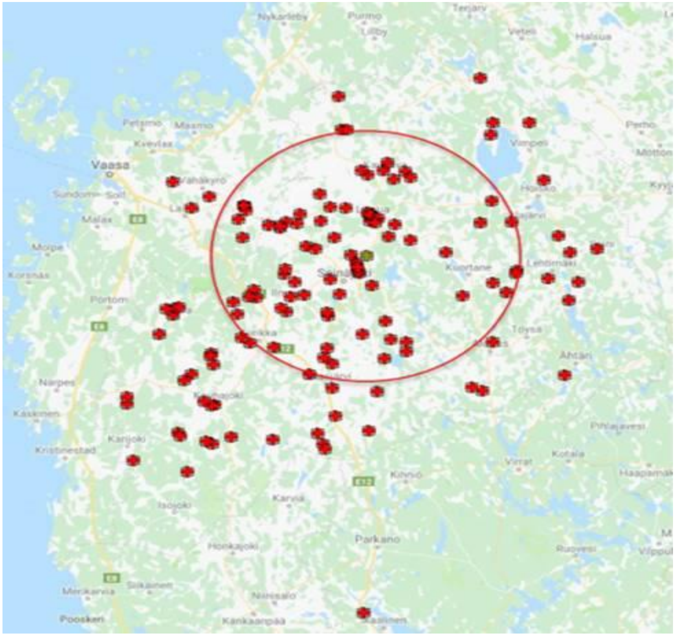

Figure 3-11 Location of arable farms with nutrient demand in the region of Nurmon Bioenergia's biogas plant. Green dot = location biogas plant Nurmon Bioenergia/slaughterhouse Seinäjoki, red dots = potential nutrient users. Red circle= 40 km radius

Nurmon Bioenergia doesn't expect any problems with viscosity of the nitrogen-phosphorus-potassium (NKP) concentrate, since the feedstock doesn't contain any sewage sludge (based on previous experience). The NPK concentrate will probably mixed with raw digestate or manure in the storages of farmers, to boost the nutrient content.

Farmers can calculate in advance how much concentrate they would like, and it is then injected in the manure storage to prevent odours of storing raw concentrate. In spring, when fertilisation is allowed, the slurry tank gets mixed and is applied on land.

As a back-up plan for disposal of the concentrate or liquid fraction of the digestate, these products could be treated in forest industry (pulping mills) waste water plants as nutrient source (nitrification-denitrification) as alternative for phosphoric acid and urea (see ANNEX I.1 Niche Markets – Nutrient source in biological water treatment of (Verbeke, Hermann, Schoumans, et al. 2021)) . However, this could render very high transport costs because of the high volume (low nutrient concentrations) and long distance (200-300 km). For this scenario the products should also be processed first, for example obtain an end-of-waste status, to get them more concentrated or ensure that there are no harmful components present which could disturb the biological active sludge system.

SWOT analysis Nurmon Bioenergia

Strengths

- Project team has long-term experience of biogas business and digestate treatment technologies.
- Nurmon Bioenergia manages the contacts with the farmers supplying manure and taking digestate products.
- Strong network of key players.
- Animal manure and slaughterhouse waste is well available in the region.

Weaknesses

- No gate-fees available from manure, no production of heat and green electricity: complete dependency on energy prices of LBG. Use of wood chips required.
- Low amount of gas and LBG fuelled trucks at the moment. Development rate of this market fast enough?

Opportunities

- Animal manure is very low utilised resource so far: possibility to copy this concept in Finland and abroad.
- Recycled nutrient products are suitable for organic farming (in Finland), which is an emerging sector.

Threats

- Unpredictability of policy environment (e.g. nutrient soil application limits, subsidies for green energy).
- Fluctuation of energy prices.

3.2.1.4 Suggestion done in SYSTEMIC and BDP

The originally planned nutrient recovery cascade contains evaporation and reverse osmosis (RO). The liquid fraction before the evaporator is acidified to pH 6 - 6.5, to ensure that nitrogen stays in the concentrate during evaporation. RO and activated carbon filtration are used for condensate treatment to ensure discharging to natural waters on site (limits: N total <15 mg/l, COD 350 mg/l, BOD 150 mg/l, P total 1 mg/l, suspended solids SS 10 mg/l). The technologies in this cascade, like the evaporator, were chosen specifically to be less heat consuming because all biogas will be converted to LBG and thus no CHP residual heat will be available. Nurmon Bioenergia therefore plans to use wood pellets to acquire the needed heat for the digestate treatment process.

If the nitrogen levels in the evaporator concentrate would create NPK nutrient ratios that are not optimal, it could be considered to stop acidification and produce ammonia water instead.

Ammonia water is directly applicable as a inorganic fertiliser product if 3% nitrogen content is achieved and provided that it is injected in the soil to minimise ammonia (NH_3) emissions. However, it remains a high risk product for fertilisation due to its high pH of 9 to 10. If the ammonia content would be high enough i.e. minimally 10 % total N according to (Brañas and Moran 2016), another option would be to try to market it towards the fertiliser industry. Yet, this could only be economically feasible (cfr. transport costs) if an ammonia processing fertiliser plant would be close by and/or ammonia sulphate crystals could be produced at the biogas plant. Other options for this product could be to use it as DeNOx reagent for flue gas cleaning in incineration plants (Verbeke, Hermann, Schoumans, et al. 2021). Examples have shown that at first sight, these are technically feasible marketing routes, however they will have to be worked out in more detail to evaluate if they would be eventually economically feasible for the business case of Nurmon Bioenergia.

Also, it can still be decided to for example add an N stripping-scrubbing unit before the evaporator or a scrubber after it without previously acidifying the liquid fraction. In this way the nitrogen can be caught in an ammonium salt solution (as liquid fertiliser) instead of in the evaporator concentrate.

The NUTRICAS Tool was used to simulate these alternative scenarios on the liquid fraction of digestate. First the originally planned scenario with evaporation and RO was simulated ("simulation 1", ANNEX I.6.1 Liquid fraction acidification + evaporation + RO

).

NUTRICAS produced slightly different results for the initially planned scenario (ANNEX I.6.1 Liquid fraction acidification + evaporation + RO

) than was originally estimated by Nurmon Bioenergia own calculations (Table 3-16). However, the results were quite close to each other which is normal since the Nurmon Bioenergia case was used to model and validate this specific technology cascade in the NUTRICAS Tool.

Then the alternative scenarios of nitrogen stripping and scrubbing before evaporation ("simulation 2", ANNEX I.6.2 N stripping-scrubbing + acidification + evaporator + RO

) and evaporation without acidification combined with condensate nitrogen stripping and scrubbing ("simulation 3", ANNEX I.6.3 Evaporation + N stripping-scrubbing + RO

) were simulated. Each simulation also included a final RO polishing step.

According to the NUTRICAS simulation, simulation 3 seems an interesting option as alternative configuration of the originally planned cascade (simulation 1). The estimated CAPEX of simulation 3 (2,937,750 €) is naturally a little bit higher than in the original scenario (simulation 1: 2,686,667 €) as there is more technologies included into this cascade.

For simulation 3, the total yearly costs per tonne of liquid fraction is estimated at 9.3 €/tonne of liquid fraction compared to the original scenario (estimated 9.2 €/tonne of LF). Moreover, a separate storage tank would be needed for ammonium sulphate (AS) which is not taken into account by NUTRICAS. However, this cascade has shown its potential and will be taken into more detailed evaluation in the ongoing final planning of the project. Benefits and marketing revenues of producing a pure single nitrogen fertiliser (AS) and an low nitrogen-high potassium evaporator concentrate instead of only NPK evaporator concentrate with a high nitrogen/phosphorus ratio of 12.6, need to be carefully evaluated. However, there is potato growing in the area and potatoes need more potassium, which might be interesting crops for application of this kind of low nitrogen-high potassium products.

The other alternative cascade of nitrogen stripping and scrubbing followed by evaporator (simulation 2) seems to produce slightly higher volume of liquid products, which would mean that more storage capacity and transport costs would have to be foreseen. Additionally, a much higher CAPEX compared to the other simulations makes this one less interesting. E.g. the most likely yearly costs of simulation 2 were estimated at 14.2 €/tonne of liquid fraction.

However, AS solutions from both N stripping-scrubbing cascades would qualify with the RENURE criteria proposed in the SAFEMANURE report in 2020 (Huygens et al. 2020; Table 2-1), making it a possible alternative to synthetic N fertilisers in the future. This could improve the revenues for this product, however it is still unsure how much this could be.

Nurmon Bioenergia evaluates the simulated CAPEX for evaporator slightly optimistic in every scenario and the CAPEX of the N stripping and scrubbing too high in scenario 2, which naturally affects its yearly costs as well. Moreover, chemical cost of sulphuric acid (H_2SO_4) has been slightly lower in Finland so far, which will also influence the yearly costs. It is also possible that evaporator can in practice be operated without antifoam which decreases the costs for about 3.2 €/tonne of liquid fraction. In general, the yearly costs of each cascade (€ per tonne of LF) seem realistic based on Nurmon Bioenergia's practical experience of similar cascades.

Nutrient recovery from the solid fraction was simulated by the **RePeat cascade** (ANNEX I.6.4 RePeat cascade on solid fraction

"). The cascade is an interesting option as it could produce high-P fertiliser (i.e. calcium phosphate sludge) and low-P soil improver which could be used more per hectare than in case of the initial solid fraction. The estimated yearly costs are still relatively high (11.7€ / tonne solid fraction) because of high chemical consumption (H_2SO_4, $Ca(OH)_2$). However, the product could be useful if there is real need to increase soil organic matter, if the calcium phosphate sludge and low-P soil improver could be marketed at higher prices by penetrating niche markets and especially if some compensation for carbon sequestration will be available in the future.

3.2.1.5 Future plans

If the biogas plant can run cost-effectively, plans are already made to expand capacity to 360 ktonne per year.

The environmental permit was obtained for 240 ktonne per year, but the environmental impact assessment has already been done for 360 kt/year. So only an update of the environmental permit would be needed. Technically an extra anaerobic digestion reactor will need to be built and extra storage capacity. Other parts of the plant have already planned for expanded capacity.

The concept of the Nurmon Bioenergia biogas plant can also be copied to other locations in Finland and other parts of Scandinavia, with tailor-made adaptations to the nutrient recovery and reuse system optimal for the new location, including new promising technologies.

3.2.1.6 Impact of SYSTEMIC

Nurmon Bioenergia has always kept in mind the possibility of setting up a second biogas plant, therefore it was very useful of being a part of SYSTEMIC. They have learnt a lot from getting to see how other large scale demo plants, with other types of feedstocks, designed their business plans and how the different technologies were performing in practice. Especially for the technologies that they themselves did not have much own experience with (e.g. RePeat, N stripping-scrubbing).

For Nurmon Bioenergia the SYSTEMIC project has been a great opportunity for networking with other plant operators and experts of nutrient recovery and reuse all over the Europe. It has been “funny” to notice that other plant operators are facing the same challenges as they have and on the other hand very inspiring to learn how these plants have been solving these problems. They have learnt a lot both from the plant operators and the research made in this project. They have had feeling that this consortium really has done important work, which enhances nutrient recovery technologies at biogas plants and has real possibility to influence legislation etc.

3.2.2 Gasum – Biogas plant Götene (Sweden)

3.2.2.1 Description of the company

Gasum is energy company owned by the Finnish state. Gasum offers natural gas, biogas and power services to the transport sector, maritime and industry. As a biogas producer Gasum owns and operates 17 biogas plants in Sweden and Finland. The Gasum Götene biogas plant is planned to be built 2023-2024 in Götene, southwest Sweden.

3.2.2.2 Business environment

Spreading regulation

The municipality of Götene is located within a nitrate sensitive area according to the regulation SJVFS 2006:66 about environmental concerns in Swedish farming. The regulation states how to calculate what amount of organic fertilisers generated from other farms that can be accepted, and also states that source documentation is mandatory when receiving manure or other organic fertilisers from others.

The spreading regulations are dependent on when the plants are deemed to be able to utilise the nutrients. After October 31th and before February 28th , fertilisers can´t be spread on fields.

There are no specific rules for manure-derived digestate. For KRAV-certified fertilisers (for organic farming) there are specific regulations when it concerns digestate from slaughterhouse waste or other industrial animal by-products (The KRAV Association 2021).

Phosphorus limits

Application of manure or other organic fertilisers are not allowed to exceed 22 kg P per ha total cultivated area (excluding fallow fields), calculated as a mean value for five consecutive years. Sometimes exceptions are made for certain crops that have a high P uptake, like potatoes and maize. In this case, a P balance of the soil needs to be kept over a five year period. In the Götene area, phosphorus is normally not the limiting nutrient agronomically.

Nitrogen limits

Götene is located in a nitrogen vulnerable zone (Figure 2-2), which implies that manure and organic fertilisers can only be applied in an amount equivalent to max 170 kg N per hectare cultivate land (excluding fallow fields), and should generally be adapted to the expected crop uptake. For autumn sown oil seed crops, max 60 kg per ha of available N can be applied, and for other crops max 40 kg available N per ha. Only the ammonium fraction is counted as available N in organic fertilisers.

Nutrient demand

Götene municipality has 405 km², and 17,500 ha agricultural land. The main cultivated crops in the region are grain wheat, barley, oats and ley (Table 3-17). Typically, the nitrogen demand is 100 – 200 kg N/ha and year for cereals and grass silage. Addition of N should be done in relation to crop demand and according to the limits of the EU Nitrate Directive. The demand for nitrogen from digestate is mainly as KRAV-certified fertilisers in organic agriculture (Chapter 12.3.5 in The KRAV Association 2021).

Table 3-17 Main crops in Götene municipality with the two neighbouring municipalities Linköping and Skara, expressed as % of cultivated land (70,000 ha; statistics from Swedish Board of Agriculture).

	% of agricultural land
Wheat and Barley	41.7
Ley	17.8
Oats	17.4
Rape seeds	5.0
Peas and field beans	4.5

Drivers for nutrient recovery

At the moment, the biogas plant would be able to use all the volume of digestate and included nutrients derived from manure in regional agriculture. Most of the raw material for the biogas plant is manure, which is currently used as a fertiliser in the area as such. Anaerobic digestion of this manure would therefore not produce problems for disposal of the digestate.

In fact, the biogas plant will produce Eco (KRAV) certified bio-fertilisers (liquid and solid fractions of digestate). The organic farming market contributes to 25% of the total crop cultivation in the area, so there is a large demand for KRAV certified organic fertilisers.

Because of co-digestion, there are more tonnes of manure derived bio-fertilisers produced than manure feedstock is delivered to the biogas plant. The excess volumes will benefit from being upgraded to other types of (KRAV) bio-fertilisers than raw digestate.

Storage during wintertime is already provided, since the required storage capacity for raw manure at farms is already existing.

Gasum estimates to be able to execute this business case a zero cost (i.e. break-even scenario), however they are interested in options to even get some extra revenues from the digestate products.

In the near future they don’t see a need for a more extensive digestate treatment. However, they want to anticipate on the changing markets and regulations by investigating possible nutrient recovery and reuse scenario’s.

Volume reduction of the digestate could decrease transport and storage costs, however the organic farming market (nearby) is very profitable and a volume reduction might not be desired from that point of view.

An added value to the organic bio-fertilisers could be if a tailor-made NPK and total solids could be accomplished for each organic farm and their cultivated crops. For this, NRR technologies might be able to provide a solution.

3.2.2.3 Business case evolution during SYSTEMIC

Feedstocks

The feedstock of Gasum Götene will be mainly dairy cow slurry, pig slurry and deep litter from cattle (Table 3-18)

Table 3-18 Origin of feedstock at Gasum Götene (estimation)

Type	Mass /year (ktonne/year)
Pig slurry	70
Dairy cow slurry	190
Deep litter from cattle	55
Chicken manure	22
Solid dairy cow manure	19
Grass silage	6
Husks	6
Fodder residues	19
Total	387

Biogas production

Biogas production is estimated to be ca. 120 GWh and will be upgraded to liquefied bio-methane (LBG).

Digestate treatment cascade

The digestate is separated in a solid and liquid fraction by means of a screw press without the use of flocculants (polymers).

This way the solid and liquid fraction can have an ecolabel (KRAV certification), making it applicable in organic agriculture.

Table 3-19 Estimated composition of the end products that will be produced at Gasum Götene (2021), including nitrogen (N), phosphorus (P) and potassium (K)

Input	Digestate		
After		Screw press	
Product	**Digestate**	**Liquid fraction**	**Solid fraction**
Mass (kton/year)	380	339	41
Dry matter (%)	10,8	7,9	35
N total (g N/kg)	6,4	6,1	8,9
NH_4-N (g N/kg)	3,4	3,5	3
P total (g P/kg)	1,2	0,9	3,8
K total (g K/kg)	3,7	2,9	10

Destination of the end products

The LBG will be sold through Gasum as a fuel for trucks. The liquid fraction will be sold as KRAV fertiliser for organic farming in the region. The solid fraction will be sold to national KRAV fertiliser producers.

SWOT analysis of Gasum Götene

Strengths

- Transfer of manure to a larger amount of bio-fertilisers applicable for organic agriculture.
- Currently no strict nutrient application limitations on surrounding agricultural soil.
- High demand of KRAV certified fertilisers.
- In-house practical experience on evaporation and N stripping-scrubbing.

Weaknesses

- High volumes of digestate and derived products cause high operational, transport and application costs.
- Current business case is "only" break-even, more positive business case to be developed.
- Located in Nitrate Vulnerable Zone, thus narrow N application limits.

Opportunities

- Reducing water content of products could reduce transport costs.
- Production of high quality peat replacement could secure even higher profit margins.

Threats

- Investment in expensive and complex digestate technologies might be 'overdoing' it.
- Market for fast-release single N fertilisers (like scrubber salts) is not profitable, because cannot be used in organic farming.
- More stringent legislation on N application, NH_4 and CH_4 emissions, organic farming might be included in the future.

3.2.2.4 Suggestion done in SYSTEMIC and BDP

Gasum believes that the nutrients in their digestate have a great value for the agriculture in the area. Therefore, they do not want to remove them in any way, e.g. nitrification-denitrification in WWTP or exporting them from the region.

The NUTRICAS Tool was used for illustrating possible nutrient recovery and reuse alternatives.

In a first NUTRICAS simulation scenario, nitrogen recovery by **N stripping-scrubbing** was studied both from the digestate and the digestate liquid fraction (details in ANNEX I.7.1 Nitrogen stripping-scrubbing

). The second simulation tests the alternative N stripping-scrubbing technology with gypsum (**FiberPlus system**) instead of sulphuric acid (ANNEX I.7.2 Fiberplus N stripping-scrubbing

). For the second scenario, Gasum would need to explore if there would be a cheap and relatively close source of Flue Gas Desuphurisation (FGD) gypsum present near the biogas plant, to make this simulation scenario feasible.

Both cascades produced ammonium sulphate solutions (AS) (N content 5-6%) which can be seen as a valuable product (production costs from 1.1 to 3.4 €/m³ of digestate) and would qualify with the RENURE criteria proposed in the SAFEMANURE report in 2020 (Huygens et al. 2020; Table 2-1). However, the volume of N stripped digestate or liquid fraction left after the nutrient recovery is only 10% lower than without NRR and the nitrogen level is half of the original. This is a disadvantage when the N stripped digestate would be used as a KRAV certified bio-fertilisers, because the nitrogen content is where the value of the product lies. Marketing the N stripped digestate outside the organic farming sector would have them fall into a lower price category. The storage, transport and spreading costs of the N stripped digestate would also be more than the expected revenue from AS (0-1€/tonne). These cascades could only be economically beneficial on a part of the digestate of liquid fraction, on the condition that a well-paying customer for AS is available (e.g. minimum 4 €/kg NH_4-N, i.e. 0.2 - 0.25 €/kg AS solution). At the moment, it would only be in the organic farming sector that this amount is paid for nitrogen, however the use of readily available, fast-release nitrogen (NH_4-N) is not allowed in this sector.

However, nitrogen recovery remains interesting because of the location of the plant in a nitrate vulnerable zone , but the cascade must contain more processes to further concentrate the nutrient products and preferably also produce dischargeable water to have also a total volume reduction.

For that reason, also cascade with evaporation and reverse osmosis (RO) was simulated in the NUTRICAS Tool as an example (Annex I.7.4 Liquid fraction acidification + evaporation + RO

). This cascade produced 112 ktonne of evaporator concentrate which contains 17.9 g N/kg, 2.7 g P/kg and 8.7 g K/kg. Mixing of the evaporator concentrate with solid fraction to increase the nutrient content and more or less tailor the NPK ratio of the bio-fertilisers could be attempted and high create even higher value products.

160 ktonne of RO permeate would be produced per year, which quality is at least close to on site discharging. If this could be discharged, a 35% less volume compared to liquid fraction should be stored or disposed of. The NUTRICAS Tool estimated the yearly cost of total cascade 8.2 €/m³ of liquid fraction, which is within a reasonable range according to Gasum and could be worth to evaluate further.

One challenge for nutrient recovery and reuse in Götene is that polymer cannot be used for solid-liquid separation as it is not allowed in end-products utilised in organic farming. That makes use of some technologies more challenging as DM content of the liquid fraction is quite high (i.e. 7.9% DM). For example, evaporation would be able to produce a more concentrated evaporator concentrate (i.e. more efficient water evaporation) if the dry matter content of the liquid fraction could be reduced by adding polymer to for example 4% DM. However, at the moment, the most interesting customer for biogas plant end-products in Götene area is the organic farming sector meaning that polymer use is not an option.

Another challenge would be to get the required heat and green energy to run the NRR processes, since Gasum would be making bio-methane or LBG from all their biogas.

As phosphorus would be the first limiting nutrient for application, it could make sense to separate P and move it to parts of the region with a higher need for it.

Phosphorus recovery from the solid fraction was also simulated with the NUTRICAS Tool in the **RePeat cascade** (ANNEX I.7.3 RePeat on solid fraction

). This cascade is currently installed at Demo Plant Groot Zevert Vergisting in a pilot/full scale size and could be an interesting option once it will be completely developed as it could produce a Calcium phosphate sludge and low-P soil improver and the CAPEX and OPEX seem to be moderate. However, the chemical cost is quite high and contributes to 80% of the total yearly cost per tonne of solid fraction.

Marketing of the end products, low-P soil improver and calcium phosphate sludge should therefore be at prices higher than 7 €/tonne to cover this yearly cost. The low-P solid fraction can be used for replacing peat in different purposes such as the potting soil industry which a very interesting niche market in Sweden.

However, in the case of Gasum Götene, the solid fraction can already be used as peat replacing soil improver, if a high DM content can be reached and thus drying the solid fraction would be needed. Low-P products can also be used to increase soil organic matter and some compensation may be available for carbon sequestration in the future.

Gasum is very interested in developing and implementing nutrient recovery technologies and they already have experience of different NRR cascades, e.g., stripping and scrubbing processes and evaporation from their existing biogas plants. Thus, they found this first evaluation with the NUTRICAS Tool very useful and could easily further explore and evaluate different options by themselves with the tool combined with their own experience.

3.2.2.5 Impact of SYSTEMIC

Gasum was only involved at a later stage in the SYSTEMIC project as an Associated Plant in 2020. They attended and contributed to many of the Online Living Lab discussions on technologies[10].

They also suggested that there was a need for an in-depth training on the use of polymers to improve digestate separation[11], which the SYSTEMIC consortium organised shortly after.

After some initial Outreach Locations were not able to be involved in SYSTEMIC and Gasum was eager to learn more about nutrient recovery and reuse in practice, they joined the final Living Lab meeting (12-13 October 2021[12]), as an Outreach location. This way, they were able to exchange their experiences with evaporation and N stripping scrubbing, biogas upgrading with other plant owners and see the promising business models and technologies of Demo Plants Groot Zevert Vergisting and BENAS in practice.

All this put them on the right track in finding the best fit NRR technologies to be implemented at their biogas plants in Götene (SE) and Riihimäki (FI).

3.2.2.6 Future plans

As the plants is not yet built, Gasum is still exploring and evaluating the different possibilities for digestate treatment and marketing and disposal of the potentially produced end products.

3.2.3 BIOMECO AD (Italy)

3.2.3.1 Description of the company

Biomeco AD is a biogas plant in the region Mantova (Lombardy, Italy). The company that will build the anaerobic digestion plant is a cooperative of dairy farmers (20-25). The plant will collect and treat cattle slurry and solid fraction of slurry from the cooperative farmers and third parties. The typical structure of the farms joining the cooperative and delivering the material is as such:100-150 lactating cows and 50 - 10 ha of agricultural surface to grow crop as feed.

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[10] https://systemicproject.eu/living-labs/

[11] https://youtu.be/HrdgFzM0_-M

[12] https://systemicproject.eu/living-labs-meeting-a-groot-zevert-demo-plant

The optimal digestate processing technologies for Biomeco still need to be chosen, designed and implemented. The LIFE DOP project[13] has already investigated for this project the application of cow manure and digested cow manure and the use of specific equipment to cavitate the slurry-manure mix to make it more manageable and suitable for anaerobic digestion.

3.2.3.2 Business environment

The biogas plant will be located in the Lombardy Region. It is one of the more industrialised and intensively cultivated areas in Europe. The total agricultural land consists out of 1 million ha and has approx.. 1,553,782 cows (30% of total in Italy), 4,857,700 pigs (40% of total in Italy). Therefore, the plant is located in a region with manure and N surplus (Figure 2-2, Figure 2-4).

Spreading regulation

Manure slurry is generally spread in winter time without injection, but it should only be incorporated in the soil within 12 hours. Injection is only compulsory when the air quality is poor (i.e. >2.5PM). Anaerobic digestion of manure and application of digestate by soil injection or fertigation are not common practices in this area.

Phosphorus limits

There are no limits for phosphorus spreading in the region.

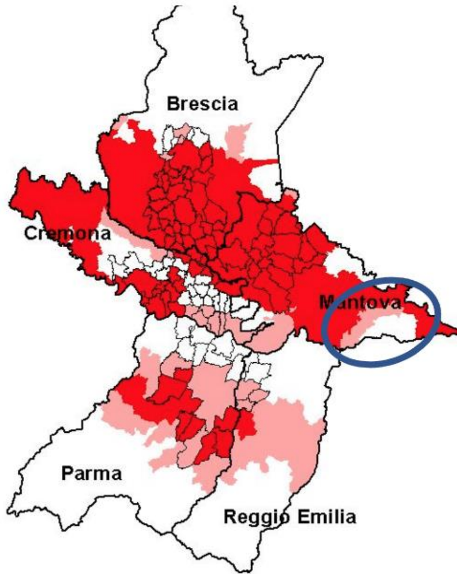

Figure 3-12 Nitrate vulnerable zones in the region of Biomeco AD plant. Pink: municipalities partially included in vulnerable zones. Red: municipalities completely included in vulnerable zones. Circle: location of Biomeco AD.

Nitrogen limits

The area for digestate spreading is classified half as vulnerable zone (170 kg N/ha) and half not (340 kg N/ha according to good practices) (Figure 3-12).

Nutrient demand

Main cultivated crops in the region are maize and alfalfa (four years crop, cut twice a year), thus the average N demand is about 200 kg N/ha, including just crop demand and not nutrient use efficiency (NUE).

Drivers for nutrient recovery

Being located in a nitrate vulnerable zone with a local surplus of cow manure makes the farmers' cooperation look for alternative ways to create end product that better meet the crop nutrient (N) demand.

3.2.3.3 Business case evolution during SYSTEMIC

Feedstocks

The feedstock of Biomeco is liquid slurry and solid manure or separated solid fraction of slurry from own farmers in the cooperation (Table 3-20).

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[13] www.Lifedop.eu

Table 3-20 Origin of feedstock at BIOMECO AD (estimation for when plant will be operational)

Type	Mass /year (ktonne/year)
Solid manure or separated solid fraction of slurry	64
Liquid slurry (7%TS)	64
Total	128

Biogas production

The biogas plant will be producing around 14,000 Nm^3 of biogas/day.

The plant will apply for new incentive scheme for the production of advanced biomethane to be injected in the grid. The average gross revenues for methane in 20 years will be around 0.60 €/Nm^3 of bio-methane.

Digestate treatment cascade

Biomeco envisages the following digestate treatment model:

- Separate the digestate with a decanter centrifuge;
- And finally treat on average 50% of the liquid fraction of digestate by a membrane based system to dischargeable water in order to produce some concentrated fertilisers that can be more easily exported.

Table 3-21 Estimated composition of the planned liquid fraction after decanter centrifuge at Biomeco AD, including nitrogen (N), phosphorus (P) and potassium (K).

	Liquid fraction
Mass (ktonne/year)	
Dry matter (%)	3-5%
N total (g N/kg)	4.5
NH_4-N (g N/kg)	3 - 3.5
P total (g P/kg)	0.1 - 0.2
K total (g K/kg)	4.5 - 5.2

Labour

For operation of the plant two people are foreseen, for the digestate treatment there is a full service and maintenance services foreseen, no internal staff involved.

Energy

No CHP energy (electricity and heat) is available, as the system does not convert biogas in CHP but produces biomethane.

Destination of the end products

- Use of the solid fraction as organic fertilisers in the surrounding non-livestock areas.
- Use of liquid fraction locally as fertiliser by injection or fertigation, using it in order to avoid chemical fertilisers for maize.

3.2.3.4 Suggestion done in SYSTEMIC and BDP

In the best case scenario, a liquid fraction with 3% dry matter can be achieved by separation in a decanter centrifuge without any additives like polymers.

The NUTRICAS Tool estimates that this quality of liquid fraction can only be obtained if a **raw digestate has a DM content of 5% or lower**. With this LF, the NUTICAS tool estimates (ANNEX I.8.1 Centrifuge (no additives) + microfiltration + reverse osmosis + ion exchange

) that the technology cascade MF + RO + IE treating 50% of the obtained liquid fraction (56,320 tonnes/year) would be feasible for an average cost of 2.2 - 3.1 €/tonne of liquid fraction or 1.1 - 1.6 €/tonne of digestate when including the cost for centrifuge.

However, if the **digestate has a higher DM content than 9%**, centrifuge separation without additives would produce a liquid fraction up to 5% DM (Table 3-21 and ANNEX I.8.1 Centrifuge (no additives) + microfiltration + reverse osmosis + ion exchange

), and it will not be possible to achieve with microfiltration a liquid fraction of 1 - 1.5% DM before entering the RO.

In this case, dilution of the liquid fraction after centrifuge with a factor 1:0.7 (mass LF:mass water) could lower the DM content after microfiltration to the required 1.5% to enter the RO (ANNEX I.8.1 Centrifuge (no additives) + microfiltration + reverse osmosis + ion exchange

). This would require 39,424 tonnes of water per year would have and average yearly cost of 3.2 - 4.1 €/tonne of liquid fraction processed in the microfiltration (56,320 tonne before dilution) or 1.5 - 2.0 €/tonne of digestate when including the cost for centrifuge.

Also permeate from RO or IE could be used for this dilution. Recirculation loops were not included in the NUTRICAS Tool, so the water mass balance and effect on the separation efficiency of the RO would need to be investigated further in practice before making the investment.

Another alternative to processing **raw digestate with DM up to 9%** could be to implement centrifuge without polymers, combined with dissolved air flotation (DAF). In this case, the technology cascade MF + RO + IE treating 50% of centrifuge liquid fraction in the DAF (ANNEX I.8.3 Centrifuge (no additives) + DAF + microfiltration + reverse osmosis + ion exchange

) would be feasible for an average cost of 2.3 – 4 €/tonne of liquid fraction processed in the DAF (56,320 tonnes/year) or 1.2 – 2 €/tonne of digestate.

Alternatively, **raw digestate with DM up to 6%** could produce a LF of 3% dry matter according to the NUTRICAS estimation if additives would be used in the decanter centrifuge to optimise the separation efficiency (ANNEX I.8.2 Centrifuge (+ additive) + microfiltration + reverse osmosis + ion exchange

). In this case, the technology cascade MF + RO + IE treating 50% of the obtained liquid fraction (62,656 tonnes/year) would be feasible for an average cost of 2.1 – 3 €/tonne of liquid fraction or 2.7 - 3.1 €/tonne of digestate when including the cost for centrifuge + additives. This is under the condition that all 128 ktonne of digestate per year are separated in the centrifuge with polymers. The estimated cost from polymer contributes greatly to the total cost, i.e. 64 tonnes powder polymer per year contributes to 50% of the estimated yearly total cost.

This can be reduced by only separating half the amount of digestate with polymer and sending this to the digestate treatment cascade (MF + RO + IE), and separating the other half without polymers. This would reduce the amount of polymer consumption to 32 tonnes per year, making the total yearly costs 2.0 - 2.4 €/tonne of digestate. This would be a cost reduction of 25% of the yearly total costs.

To conclude, the NUTRICAS Tool estimates that for digestate with higher DM content (6-9%) the cascade with dilution of the LF or with DAF the costs would be similar (i.e. 1.5 - 2.0 €/tonne of digestate).

For digestate with lower DM content (5-6%) the use of polymer in the centrifuge is advised.

It is important to note that marketing revenues and disposal costs are not included in the NUTRICAS simulations and that this needs to be studied further before making a final investment decision.

Also, since Biomeco will not have residual heat and green electricity available, a detailed energy balance should be made so see where these are required in the digestate process, what the cost will be and if there are other sources of green energy nearby to cover these needs.

3.2.3.5 Impact of SYSTEMIC

Biomeco only joined SYSTEMIC in the final months of the project. Contributing to this report and the suggestions made in this report might contribute to which technologies for nutrient recovery and reuse will finally be implemented at the biogas plant.

3.2.3.6 Future plans

Biomeco still needs to study in detail all possibilities of technologies and evaluate them before the make an investment decision.

4 Discussion and conclusions

Involvement of the Outreach Locations

Dedicated involvement of biogas plants in an H2020 project requires a lot of time and commitment to the project's content, a relation with the consortium based on trust and a certain degree of innovative entrepreneurship from the Outreach Locations. Most of the Outreach Locations biogas plants (7 out the initial 11: Figure 2-1, A) have shown this dedication throughout the lifetime of the project and will probably stay in touch with the project consortium afterwards. Since the OL were only involved on voluntary basis, it was a natural process that some of them were not able to stay involved in the project or only to a lesser extent. This was the case for:

- At **Biogastur** (Spain) a reorganisation and management take-over caused them to withdraw from the project in 2018.
- The contact person at **Emauraude BioEnergie** (France) changed position within the company in summer 2021 and all contact with them as OL have been lost since then.
- **Somenergia – Biogas plant Makassar** (Spain) and **Greengas AD** (Ireland) did not have the time or intention anymore to be involved as OL and therefore simulations with the NUTRICAS Tool could not be executed for their cases. The last version of their fact sheets has been added under ANNEX II for completeness.

RIKA BioTech-Fridays (United Kingdom) was first one of the five SYSTEMIC demo plants, but was exchanged with OL Waterleau NewEnergy because the plant in Kent, UK (Fridays) was not yet build. RIKA BioTech is also a project developer instead of one biogas plant, which makes them a bit different from the other OL. Their designed technology concept for the Fridays plant was relying on very specific technologies and the project was sold to another project developer, GreenCreate. The design of the project (i.e. biogas plant and NRR technologies) and commissioning have since then changed from the initial plans designed by RIKA biotech. Therefore, the RIKA biotech-Fridays Outreach Location has been included in ANNEX 0 and no "Suggestion from SYSTEMIC and BDP" could be written, because there was no direct link anymore with the plant owners or current project developers at Fridays.

For both **Nurmon BioEnergia-Atria** (Finland) and Fridays-Rika Biotech/GreenCreate, the business cases were described in detail in Hermann and Hermann (2020a) and financial KPIs have been calculated in Hermann and Hermann (2020b)[14].

Potential for implementation of NRR technologies at the Outreach Locations

The design of an economically feasible and sustainable technology cascade cannot be generalised and is frequently tailor-made to optimise the biogas plant's business case within its specific business environment. Additionally, a specific technology cascade can prove cost-effective for a one biogas site and not for another, depending on the local boundary conditions in which the plant is operating.

This includes **external boundary conditions** related to a biogas plant, like the regional regulations for operating the biogas plant and NRR technologies, transport and use of the end products, premiums and incentives and the market for end products.

Internal boundary conditions seem to have less influence at first sight, but can also "make or break" a business during the development and implementation. These include for example

- the scale of the biogas plant
- the available space on site
- the available storage capacity
- integration of new nutrient recovery and reuse technologies within the existing configuration of technologies at the plant

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[14] Full reports available at https://systemicproject.eu/downloads/ → "Project Deliverables"

- availability of residual heat and/or re-usable water
- technical know-how of the staff
- entrepreneurship and innovativeness of the biogas plant owner or site manager

Advanced digestate treatment to purified or dischargeable water

Many of the OL were interested in the NRR cascades that could reduce the volume of the digestate by producing dischargeable water, i.e. membrane filtration + reverse osmosis, evaporation + reverse osmosis or drying. The technology cascade "Microfiltration and RO + ion exchange" has proven its efficiency in wastewater treatment and desalination. Additionally, there are more and more SMEs, mainly in the Netherlands, successfully implementing these cascades on manure or digestate.

Yet for these input streams with higher dry matter and organic matter and particle size levels compared to wastewater, clogging and fouling of the membranes are the most common problem, leading to reduced performance and output flows. This can leads to increased operation costs, having an impact on the operation business case. Especially the reverse osmosis membranes are very sensitive to fouling: as a rule of thumb only a dry matter content of <1.5% should be present in the input stream that enters the RO. To achieve this an advanced pre-treatment of the digestate, including steps like optimal separation (including additives like flocculants), a DAF unit, paper filters or dilution of the RO input could be implemented. This was illustrated by the NUTRICAS simulations done for Biomeco AD.

For a continuously well-performing "microfiltration and RO + ion exchange" cascade, regular chemical cleaning steps are needed with acidic or alkaline media, surfactants, chelants, oxidants oxidants, should be used to recover the capacity of the membranes (Shi et al. 2018). These costs have been estimated and included in the NUTRICAS cost estimation. Still, this is under the condition that experienced operating staff is present and that the cleaning regime is be optimised for the specific type of digestate. Consequently, the NUTRICAS simulations do not take into account additional costs for calamities: e.g. unexpected foaling and clogging of the membranes and the required early replacement. This could increase the costs significantly, estimated up to 10-40% of the CAPEX or even more depending on how often the membranes need to be changed. It is therefore very difficult to estimate the OPEX of a membrane filtration cascade in advance at the stage of making a decision of investment. The SYSTEMIC consortium and technology providers therefore advice to do pilot tests of the membrane filtration technology on the specific input streams that need to be processed. Preferably, pilot tests done on a longer term (e.g. several months) to take into account possible calamities like foaling and the effect of variations in the digestate composition. This way a more realistic OPEX estimation can be approached.

For the "evaporation + RO" cascade, RO membrane fouling issues are less pronounced, because the evaporator condensate represents a much cleaner input flow. However, for this cascade, the recovered end products might be more difficult to market.

It is in general important to take into consideration the marketing revenues and disposal costs of all produced end products, which are not included in the NUTRICAS tool at the moment. For the "(DAF) + microfiltration and RO + ion exchange" cascade these disposal costs could include DAF flotation sludge, microfiltration solids, RO concentrate and spent regenerant solutions. For example, for the spent regenerant solution has to be disposed by a chemical waste treatment facility and these costs can. This costs can range from 42€ to 85€ per tonne to over 840 € per tonne for respectively non-hazardous and hazardous resins (Samco 2021).

Nitrogen recovery and RENURE criteria

When selecting the nutrient recovery and reuse technologies for the NUTRICAS simulations most OL wanted to see the impact of removing from digestate and concentrating it in a separate product with low organic matter. There was clearly a link with being located in a NVZ area or with the need to anticipate on stricter application and emission limits for ammonia. The N stripped digestate could then be applied on a smaller surface of land before meeting the N application limits. The production of reverse osmosis concentrate and ammonium scrubber salts could also include a market opportunity since these are liquid

N products containing low amounts of organic matter. Therefore, they could be cheaper alternatives for synthetic N fertilisers, with a lower carbon footprint.

For all simulations with N stripping-scrubbing cascades and RO, the final AS or RO concentrates would be compatible with the proposed criteria for RENURE (REcovered Nitrogen from manURE) (Table 2-1). These are criteria that have been proposed in the SAFEMANNURE study by JRC to allow the use of RENURE products in Nitrates Vulnerable Zones above the threshold established by the Nitrates Directive (i.e. 170 kg N ha^{-1} .$year^{-1}$) (91/676/EEC) (Huygens et al. 2020).

Recycling of organic waste and manure into renewable biobased fertilisers like RENURE would contribute to reduction of use of fertilisers by at least 20% and hereby would fit into the EU Farm to Fork strategy an biodiversity strategies to achieve nutrient losses by at least 50% by 2030, while ensuring that there is no deterioration on soil fertility.

Unfortunately, the SAFEMANURE report including the RENURE criteria currently only remains a communication, which still needs to be adopted by EU regulation and on the level of the Member States. The SYSTEMIC consortium including Demo Plants, Associated Plants and Outreach plants are looking forward to the outcomes of this possible implementation and the impact on their business cases.

According to DG ENVI (de Beuckelaere 2021), currently the feedback of all Member States was collected and most of them prefer a country specific solution. This means that a Member state would be able to file a request to the commission to adopt an implementing decision allowing the Member State to use RENURE. This procedure is already foreseen in EU legislation and is also used for the Nitrate Directive: "applying for a derogation". For a derogation, the Commission would be able to include binding conditions of use linked to the safe application and monitoring and control requirements on productions and use. They would also be able to review the conditions based on gained experience or technological advancements. The disadvantages of this procedure would be that the conditions would be adaptable to the situation in the applying Member State, which hinders EU harmonization of the use of RENURE. It remains a heavy administrative procedure for each Member State and decisions are limited in time and subject to vote of the committee. Therefor the request for derogation would have to be renewed periodically by the Member State.

These time and geographical limitations would create uncertainty for possible investors in NRR technologies producing RENURE. However, the discussion on the implementation procedure of RENURE is not finalised yet and still a lot of other questions need to be answered before the derogation procedure for RENURE would be ready to be used. For example, will the conditions for authorization include only the proposed RENURE criteria proposed in the SAFEMANURE report or will there be more conditions added by the EC or individual member states? How and which bodies on member state level would be inspecting, monitoring the production and use of RENURE and the effect on the water quality? Because these questions are still unanswered, until today it still remains unclear what the content of an authorization dossier should be.

Another question that arises is if the RENURE "status" would in practice create sustainable and better conditions for biogas plants to market these products. Examples of biogas plants where the produced AS and/or RO concentrates are already allowed to be used above 170 kg N/ha/year show that the RENURE status would not immediately pave the way for these products to completely replace synthetic N fertilsers at the same market price. For example, Demo Plant Groot Zevert Vergisting, with pilot area "Synthetic fertiliser free Achterhoek" with temporary and spatial exemption of 170 kg N/ha limit, has farmers in the area pay ≈ 1.20 €/ kg N in their RO concentrate. This is more or less the same as they would pay for synthetic N fertilisers. However, the costs for GZV for product storage, sampling, transport to farmer, injection make that their net costs are about 8 euro per tonne RO concentrate. Producing the product therefore still represents a cost, yet it is smaller than compared to business-as-usual, namely long distance export as raw digestate (15 – 18 €/tonne).

The example of Outreach Location Biogas Bree illustrates that it is still a challenge to market AS from acid air scrubbing (i.e. possible RENURE product, already with a derogation in Flanders) at positive prices, because farmers are not used to pay for fertilisers produced from manure and because costs for storage and field application of RENURE products are typically higher than for conventional synthetic N fertilisers.

Many of the OLs confirm that convincing the farmers to use and pay for these products would still be one of the challenges to be tackled, even if the products would be acknowledged as RENURE. The situation is completely different when the biogas plant has own land available to use the derogated N products. Demo plants BENAS and Aqcua & Sole make profits from using their own AS as alternative for synthetic N fertilisers. In these cases, the RENURE status can already make a big difference economically. In general, we will still have to wait what the eventual procedure for RENURE will be and how possible RENURE acknowledgement of certain products will impact their marketing incomes in different EU regions and eventually each individual business case and certainty for investment in these nutrient recovery and re-use technologies.

Phosphorus recovery from digestate

For certain regions, phosphorus is the first limiting element when applying digestate or manure on land (Figure 2-3). Also, as seen for AD plants digesting WWT sludge, the recovery of P could be valuable for a number of reasons.

The RePeat cascade seems promising and has proven its benefits for the specific case of Demo Plant Groot Zevert Vergisting. The CAPEX of the system is relatively low, yet the OPEX is high because of the chemical consumption and high volumes of residual sludge streams and costs for product storage.

Revenues from the produced calcium phosphate sludge and low-P soil improver have also not been positive yet because the composition and form still needs to be optimised to fit the desired (niche) markets (see Deliverable.2.7 Report on Business Model Development and Application to Five Demonstration Plants).

The calcium phosphate sludge still encounters a high disposal cost as “animal manure” because of the low DM and high OM content. The low-P soil improver is currently locally used as soil improver in the Netherlands at a price of 0-5 €/m³ in the Netherlands. This is relatively low, because of competition with compost from bio-waste sources.

Preliminary market evaluations have shown that revenues for the low-P soil improver as a potting soil could reach values of 15-20 €/m³. However, the low-P soil improver still has relatively high ammonium and sulphate concentrations, which lead to high EC and, as far as ammonium is concerned, lower pH due to nitrification during cultivation. Additionally, manure-based potting soils are not yet accepted and the produced volumes are too low to meet the demand. A promising niche market could be as substrate for mushroom cultivation, replacing peat in casing soil. Here revenues up to 20 €/m³ could be expected.

However, implementation of the RePeat technology in another region, i.e. business environment, combined with further optimisation of the end products and market development in that region might have a totally different outcome and prove to be profitable after all.

One of the next steps in the RePeat research is to increase dry matter content of the P sludge by switching from the base addition of $Ca(OH)_2$ for the precipitation of calcium phosphate to the more expensive $Mg(OH)_2$ for precipitating struvite. As shown for the case of Waternet, struvite can reach positive market prices as a secondary raw material for producing mineral P fertilisers. Another high profit market for this product could be found in the niche market of organic farming. Because of a positive advice from EGTOP (EGTOP 2016), normally struvite from WWT sludge would be included in the list of allowed fertilisers in organic farming (Annex I of Regulation (EC) No 889/2008)) when the STRUBIAS ANNEX is implemented in the Fertilising Products Regulation (2019/2009) and this enters into force in 26 June 2022.

Inclusion of manure-derived struvite (for example from the RePeat cascade) still encounters some legal constraints: firstly, only non-factory farming manure can be used. Secondly, the use of sulphuric acid in the recovery process is questioned, because the Organic Farming movement would regard this as “synthetic nitrogen” derived from chemical processes, which is not preferred to be used in organic farming. The use of other synthetic reagents in recovery processes is considered acceptable, with preference to natural origin materials and with health and environmental impacts avoided. Lastly, animal By-Product “End-Points” have not yet been defined in the EU Fertilising Products Regulation (STRUBIAS study).

Nutrient recovery technologies and the use of chemicals

In general, it can be noticed that a lot of the Outreach Locations have a tendency towards lower use of costly chemicals in the nutrient recovery and reuse process. Many of them where therefore interested in a simulation of the Fiberplus cascade, because it did not require aggressive chemicals like acids for scrubbing. In the case of Gasum Götene, even the use of flocculants (polymers) was not allowed because of them marketing their end product in the organic farming sector. Many of the OL strive to achieve a good recovery rates or separation efficiencies with the lowest amount of chemicals possible, because they are aware that this has a huge impact on the OPEX. However, for this they often have to rely on consultants and chemical sales representatives, which also cost money for advice. Yet for some technologies like N stripping-scrubbing and RePeat, chemicals are unavoidable. And for technologies like membrane filtration and RO an advanced pre-treatment with additives like polymers is necessary to achieve low maintenance costs and high quality end products.

So at this stage of development in NRR, it seems unavoidable that the use of chemicals is required. Other lower cost options could be sought in alternative chemicals, like organic acids or recycled chemicals. Unfortunately, lab testing research has shown respectively their lower acidity or concentration often makes that higher amounts should be used which could undo the potential economic benefit (Regelink et al. 2019). When using recycled chemicals there could also be a risk at like higher levels of contaminants like heavy metals.

Heat requirements for NRR technologies

One of the conclusions from Deliverable 3.2 (Verbeke, Brienza, and van Dijk 2021) was that both CAPEX and OPEX of most of the NRR technologies greatly depend on the amount of heat energy from the CHP and the process that can be reused.

Since many of the OL are using CHPs, most of them have cheap residual heat available, which they often already use (partly) for NRR technologies like drying. Integrating new NRR technologies in an existing biogas plant would require an evaluation of the available and needed heat, taking into account the possible premiums for heat recovery and costs for redesigning or redirecting the heat flows.

Implementation of certain NRR technologies could in some cases only be financially feasible and sustainable if cheap green heat (from example from a CHP) is available. If not enough heat is available, this can be compensated by a better heat recovery design, which will increase the investment costs.

Therefore, the implementation of NRR technologies like N stripping-scrubbing, drying or evaporating could be hindered when biogas is valorised as bio-methane or LBG. In this case or in the case that all residual CHP heat is already dedicated to other existing processes at the plant, the heat will need to be acquired form other, preferably green and sustainable sources like from neighbouring industries, which are not always or yet available.

NRR at large scale biogas plants

The European Farm to Fork strategy has specific attention on also including also small-scale farmers and small and medium-sized enterprises (SMEs).

However, simulations of cost estimations at the Outreach Locations confirm that mainly large biogas plants, digesting high amounts of feedstocks, can have nutrient recovery technologies implemented in an economically feasible way. For example, at Nurmon Bioenergia the gate fees will be competitive due to the economy of scale and technical solutions of their biogas plant concept.

Because of their scale advantage they can easier balance the costs for digestate processing with the steadily rising costs for land application or can offer competitive gate fees or develop more efficient marketing strategies.

The scale disadvantage of the smaller AD plants and farms can be decreased by including them in integrated bio-refinery systems. For example, setting up closed loop-cooperations or partnerships with other biogas plants, farms, waste processing industries, contractors, agricultural advisors etc. to efficiently and at low cost for all involved parties recycle and exchange energy, water, nutrients on a regional scale. This could lead to shared marketing costs, shared investment capital, and reduced risk. Larger cooperatives would also enjoy an improved negotiating position with larger purchasers (Dahlin, Herbes, and Nelles 2015).

Cost estimations made by the NUTRICAS Tool

According to the OL, the NUTRICAS Tool has proven to be a very interesting tool for exploring the possibilities of different NRR technology cascades at a glance. The tool does have a tendency to sometimes underestimate the CAPEX and OPEX, since these values are based on a relatively short list acquired from literature and practice . The CAPEX did not include the possible need for extra storage and the OPEX is estimated as one lump sum (i.e. a percentage of the CAPEX) based on values which often did not include a detailed cost breakdown or the specific costs related to heat consumption and availability (see Deliverable 3.2). When the NUTRICAS Tool will be used more often, users will adapt the CAPEX and OPEX to their own opinion, which will render more accurate data that can be used to improve the cost estimation model, providing more reliable results (Verbeke, Hermann, Brienza, et al. 2021b).

For now, when interpreting the chapters on the OL in this report, it is therefore important to take into account this cost underestimation and apply an additional safety margin. Also, for each specific OL the additional revenues from marketing and costs for disposal of all the recovered products, gate fees and additional general costs or subsidies and premiums have to be taken into account to make a realistic and detailed cost estimation. For this, they will have to ask more exact values from offers of technology suppliers and advice from contractors, agricultural advisors, end consumers etc.

Advice from SYSTEMIC on implementation of NRR technologies

We have seen that certain OL did not yet have sufficient drivers for considering the implementation of NRR technologies (e.g. Biogas Bojana, Ferme du Faascht). For them it would be “gold-plating” to recover nutrients and water at this moment, because raw digestate can for their case still be considered as a valuable fertiliser and soil improver. However, only under the condition that it is applied as local as possible, preventing nutrient and methane emissions and leaching by taking into account weather conditions, soil type and nutrient content and crop nutrient demand.

Nonetheless, for these regions it would still be beneficial if biogas plants would investigate and evaluate their options for nutrient recovery and reuse technologies, to be able to anticipate to the possibility of more stricter application rules in the near future.

It is therefore recommended to take sufficient time for designing and deciding upon the investment of a site specific digestate treatment cascade that balances all the money, mass and energy flows and is flexible for future changes.

With the presented Business Development Package, the SYSTEMIC consortium hopes to provide all required information and contacts to help biogas plants in implementing nutrient recovery and reuse at their plants. This will eventually help them on their way towards implementing circular economy in the sector of biogas production.

5 Expected impact

The BDP will be publicly available and in combination with the developed dissemination plan will tend reach out beyond the group of SYSTEMIC Outreach Locations.

Next to the expected impact of the availability of the BDP (Deliverable 3.6), involvement of the OL in SYSTEMIC and the application of the BDP to their business case has been contributed to the following expected impact Key Performance Indicators as were defined in the Grant Agreement.

Unfortunately, a quantification of the impact KPIs was in most cases not possible.

First steps of the Outreach Locations (first followers) towards implementation of enhanced nutrient recovery technologies (TRL 7-8)

Several Outreach Locations have been making use of the SYSTEMIC network to investigate the effect of implementing NRR technologies in their business case.

Concrete examples are:

- Waterleau NewEnergy: small-scale lab trials of WNE to produce crystallised ammonium sulphate. evaluating marketing possibilities for different types of potential end products and synergies with other companies.
- Biogas Bree: communication with other biogas plants and even pilot testing to evaluate different types of evaporation systems..
- GMB: pilot tests with N stripping-scrubbing technology from Nijhuis Saur (partner in SYSTEMIC).

Eventually some of them have made investing decisions:

- Biogas Bree: purchase of a new fluidised bed dryer and no evaporation system.
- Biogas Bojana: purchase of a specialised belt dryer instead of a regular belt dryer.
- GMB: decision of investment in an N stripping-scrubbing unit expected.
- Ferme du Faascht: extension of the general capacity of the plant including rainwater reuse, optimization of heat reuse and possibility within the plant’s design to include NRR technologies.
- Nurmon Bioenergia: building of the original biogas plant design with NRR foreseen for 2022, yet with possibility within the plant’s design to include other NRR technologies.
- Waternet: extracting more phosphorus from sludge digestate ashes.

100% reuse of the recovered mineral nutrients as (raw material for) fertilisers

GMB and Waternet are currently the only OL where nutrients from the digestate is not 100% recovered as (raw material) for fertilisers. For wastewater (sludge) treatment plant Waternet, the ammonia is not recovered from the digestate because, the large volumes of digestate (650 kton per year) would require too much scrubbing acid to recover the nitrogen in a way that would be economically comparable to their current practices. Also, nitrification-denitrification is still the best available technology for waste water treatment including their large volumes of liquid fraction of digestate after decanter centrifuge.

GMB’s BIR BV biogas plant is considering the investment in N stripping-scrubbing unit, which would result in them recovering 80% of their total ammonium (NH_4-N) load.

Creating new business opportunities for the valorisation of biowaste at AD plants

In each Chapter of this report under “Suggestion of SYSTEMIC and the BDP” a detailed description is provide about how new business opportunities for each OL were suggested and might have potential for each case. Creating new business opportunities for fertiliser industry and fertiliser retailers in trading secondary fertilisers in the European market

Waternet will market the extended volumes of struvite to ICL fertilisers as secondary raw material for P fertilisers.

Ammonium sulphate from multiple OL (e.g. Biogas Bree, GMB, Waterleau) is traded and used as alternative to conventional synthetic N fertilisers.

Biogas Bree plans to further invest in getting their dried digestate pellets in the organic fertiliser retail market.

Improving the competitiveness of the agro-industry by reducing the costs for disposal of manure, sludge and organic waste with 20% and costs for biogas production with 15%, and reducing CO_2 emissions from manure transport by 60-80%.

By using evaporation systems and drying systems plants like Nurmon Bioenergia, Gasum, Biogas Bree, Waterlau NewEnergy, Waternet and GMB are reducing the transport distances for disposal compared to business-as-usual (i.e. long distance exporting) and consequently also the cost related to application and storage. It was not possible to quantify the cost reductions for the OL.

Creating a leading position for European engineering companies offering sustainable nutrient recovery technologies for manure, sewage sludge and biowaste

The Outreach Locations will first look at European engineering companies involved in the network of SYSTEMIC because of the value of demonstration and experience exchange during the project.

Creating ± 50 high quality jobs per factory in rural areas

Implementation of the NRR technologies at the OL have shown to create between 1 and 5 jobs on site per NRR technology. Creation of jobs indirectly linked to implementation of NRR technologies, for example in the technology engineering companies, retail-and fertilizer business, contracts for spreading, etc. cannot be measured.

Reducing Europe's dependency on external phosphate reserves by 20 to 30%

Waternet does make great efforts in recovery of phosphorus as secondary raw material for mineral P fertilisers, and is planning to increase the amount of recovered phosphorus by implementing a P leaching system from digestate ashes. Waternet is actively demonstrating their P recovery systems and providing trainings on struvite precipitation in practice from digested sludge. This will encourage other (sludge processing) biogas plants to follow their example.

Other plants, like Biogas Bree, Gasum, Atria, etc. are already focusing on creating (dried) products that better fit to NPK nutrient demands by crops, which also contributes to less use of 'fossil' (mined) mineral P fertilisers.

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I. ANNEX I – detailed NUTRICAS simulations per plant

I.1 Biogas Bojana: NUTRICAS scenarios

I.1.1 Nitrogen stripping-scrubbing

On raw digestate

Calculation model: "CO_2 stripping to pH 8.8, 65°C, 80% of NH_4-N stripped"

	Digestate	Ammonium sulphate solution	N stripped digestate
After		N stripping-scrubbing	
Mass (tonne/year)	65,600	3,082	62,748
Total DM (%)	7.2	1.2	7.8
N total (g N /kg)	3.7	20.5	2.9
NH_4-N (g N/kg)	1.2	20.4	0.3
P total (g P/kg)	0.9	0.001	0.9
K total (g K/kg)	2.0	0.004	2.1

Concentration AS solution: 96 g $(NH_4)_2SO_4$/ kg AS solution = 9.6 % AS solution

N stripping-scrubbing	Most likely	Minimum	Maximum	Remarks
CAPEX (€)	473,833	375,000	500,000	
OPEX (€/year)	17,058	135,00	18,000	3.6% of CAPEX
H_2SO_4 96% (€/year)	32,147	230 Tonne/year		0.14 €/kg
Yearly cost (€/year)	80,794	70,647	83,481	CAPEX: 15 years depreciation
Cost (€) / m³ digestate per year	1.2	1.1	1.3	

Marketing revenues for ammonium sulphate (AS) and N stripped digestate (total mass of 65,830 tonnes per year) should at on average 1.1 - 1.3 €/tonne product to be break even with the yearly CAPEX and OPEX.

I.1.2 Fiberplus N stripping-scrubbing

On raw digestate.

Calculation model: "CO_2 stripping to pH 7.8, 80°C, 80% of NH_4-N stripped (excluding fiber extraction and paper making). A waste product, flue gas desulphurization (FGD) gypsum is used as scrubbing agent.

	Digestate	FGD Gypsum 73%	N stripped digestate	Ammonium sulphate solution	Calcium carbonate
After			Fiberplus N stripping scrubbing		
Mass (tonne)	65,600	533	61,466	2,792	1,875
Total DM (%)	7.2	75	5.7	12.6	67.5
N total (g N /kg)	3.7	0.3	2.8	18.1	9,3
NH_4-N (g N/kg)	1.2	0.1	0.3	18.0	6,7
P total (g P/kg)	0.9	0.1	1.0	0.002	0,154
K total (g K/kg)	2.0	0.2	2.1	0.001	0,30

Concentration AS solution: 85 g $(NH_4)_2SO_4$/ kg AS solution = 8,5 % AS solution

Fiberplus N stripping scrubbing	Most likely	Minimum	Maximum	Remarks
CAPEX (€)	1,275,000	1,150,000	1,400,000	
OPEX (€/year)	45,900	41,400	50,400	3.6% of CAPEX
FGD Gypsum 73% (€/year)	6,396	533	6,396	0.012 €/kg
Yearly cost (€/year)	13,7296	12,4463	15,0130	CAPEX: 15 years depreciation
Cost (€) / m³ digestate per year	2.1	1.9	2.3	

Marketing revenues for $CaCO_3$, AS and N stripped digestate (66,133 tonnes per year) should at on average 1.9 - 2.3 €/tonne product to be break even with the yearly CAPEX and OPEX.

I.2 Ferme du Faascht: NUTRICAS scenarios

I.2.1 Nitrogen stripping-scrubbing

Calculation model: "CO_2 stripping to pH 8.8, 65°C, 80% of NH_4-N stripped"

	Liquid fraction	Ammonium sulphate solution	N stripped digestate
After	Screw press	N stripping-scrubbing	
Mass (tonne/year)	13000	624	12,490
Total DM (%)	5	1.0	6.0
N total (g N /kg)	6.0	50.1	3.7
NH_4-N (g N/kg)	3.0	50.0	0.6
P total (g P/kg)	0.8	0.001	0.9
K total (g K/kg)	1.9	0.00	2.0

Concentration AS solution: 282 g $(NH_4)_2SO_4$/ kg AS solution = 28% AS solution

N stripping-scrubbing	Most likely	Minimum	Maximum	Remarks
CAPEX (€)	87,500	50,000	100,000	
OPEX (€/year)	1,838	1,050	2,100	2.10% of CAPEX
H_2SO_4 96% (€/year)	15,927	114 Tonne/year		0.14 €/kg
Yearly cost (€/year)	23,597	20,310	24,693	CAPEX: 15 years depreciation
Cost (€) / m³ liquid fraction per year	1.8	1.6	1.9	
Cost (€) / m³ digestate per year	1.5	1.3	1.5	

Marketing revenues for AS and N stripped digestate (total mass of 13,114 tonnes per year) should at on average 1.5 - 1.9 €/tonne product to be break even with the yearly CAPEX and OPEX.

I.2.2 Fiberplus N stripping-scrubbing

Calculation model: "CO_2 stripping to pH 7.8, 80°C, 80% of NH_4-N stripped (excluding fiber extraction and paper making)

	Liquid fraction	FGD Gypsum 73%	N stripped digestate	Ammonium sulphate solution	Calcium carbonate
After	Screw press		Fiberplus N stripping scrubbing		
Mass (tonne/year)	13,000	264	12,299	570	396
Total DM (%)	5	75	4.1	12.8	68.6
N total (g N /kg)	6.0	0.3	3.7	43.9	18.8
NH_4-N (g N/kg)	3.0	0.1	0.6	43.8	15.8
P total (g P/kg)	0.8	0.1	0.9	0.002	0.132
K total (g K/kg)	1.9	0.2	2.0	0.001	0.27

Concentration AS solution: 226 g $(NH_4)_2SO_4$/ kg AS solution = 22.6 % AS solution

Fiberplus N stripping scrubbing	Most likely	Minimum	Maximum	Remarks
CAPEX (€)	725,000	600,000	850,000	
OPEX (€/year)	30,450	25,200	35,700	4.2% of CAPEX
FGD Gypsum 73% (€/year)	3,169	264	Tonne/year	0.012 €/kg
Yearly cost (€/year)	81,952	68,369	95,536	CAPEX: 15 years depreciation
Cost (€) / m³ liquid fraction per year	6.3	5.3	7.3	
Cost (€) / m³ digestate per year	5.1	4.3	6.0	

Marketing revenues for $CaCO_3$, AS and N stripped digestate should at on average 5.2 - 7.2 €/tonne product to be break even with the yearly CAPEX and OPEX.

I.2.3 Microfiltration + reverse osmosis (+ ion exchange)

- Separation of the digestate by means of the screw press without addition of flocculants (polymers): already present at the plant of Ferme du Faascht.
- Further purifications of the liquid fraction by means of microfiltration and reverse osmosis.
- Optionally ion exchange to create a permeate that is dischargeable in surface water.

Calculation model: "microfiltration + reverse osmosis + ion exchange"

	Liquid fraction	Solids	MF permeate	RO concentrate	RO permeate	Regeneration salts	Purified water
After	Screw press	MF		RO		IE	
Mass (tonne/year)	13,000	5,304	7,696	3,611	4,188	460	4,146
Total DM(%)	5.0	9.2	2.1	6.1	1.0	9.1	0.01
N total (g N /kg)	6.0	9.4	3.7	7.1	0.6	5.1	0.0004
NH_4-N (g N/kg)	3.0	3.0	3.0	5.7	0.5	5.0	0.0003
P total (g P/kg)	0.8	1.8	0.13	0.27	0.003	0.03	0.0001
K total (g K/kg)	1.9	2.0	1.8	3.7	0.2	1.4	0.00005

Dry matter content of liquid fraction after microfiltration is too high to enter the reverse osmosis units. This should preferably be below 1.5-1% DM. To achieve this, dilution would be necessary (at least 1:2.25; meaning adding 1.25 tonnes of water per tonne of MF permeate.

Microfiltration	Most likely	Minimum	Maximum	Remarks
CAPEX (€)	49,500	25,000	100,000	
OPEX (€/year)	495	250	1,000	1% of CAPEX
Yearly cost (€/year)	3,795	1,917	7,667	CAPEX: 15 years depre-ciation
Cost (€) / m^3 liquid fraction per year	0.29	0.15	0.59	
Cost (€) / m^3 digestate per year	0.24	0.12	0.48	

Reverse osmosis	Most likely	Minimum	Maximum	Remarks
CAPEX (€)	95,000	80,000	110,000	
OPEX (€/year)	1,900	1,600	2,200	2% of CAPEX
Dilution water		9,620 tonne/year		
H_2SO_4 96% (€/year)	14,373	103 tonne/year		Acidification membranes 0.14 €/kg
H_2SO_4 37% (€/year)	2,044	16 tonne/year		For CIP 0.13 €/kg
Na(OH) 30% (€/year)	1,970	6	tonne/year	For CIP 0.35 €/kg
Yearly cost (€/year)	26,621	25,321	27,921	CAPEX: 15 years depreci-ation
Cost (€) / m^3 liquid fraction per year	2.05	1.95	2.15	
Cost (€) / m^3 digestate per year	1.66	1.58	1.75	

Ion exchange	Most likely	Minimum	Maximum	Remarks
CAPEX (€)	4,000	3,500	5,000	
OPEX (€/year)	40	35	50	1% of CAPEX
Flushing water		419 tonne/year		
H_2SO_4 96% (€/year)	11	0.07 tonne/year		Regeneration 0.14 €/kg
Na(OH) 50% (€/year)	51	0.12 tonne/year		Regeneration 0.4 €/kg
Yearly cost (€/year)	0.028	0.025	0.034	CAPEX: 15 years depreci-ation
Cost (€) / m^3 liquid fraction per year	0.023	0.021	0.028	
Cost (€) / m^3 digestate per year	0.028	0.025	0.034	

Total cascade	Most likely	Minimum	Maximum
Yearly cost (€/year)	30,784	27,567	36,032
Cost (€) / m^3 liquid fraction per year	2.37	2.12	2.77
Cost (€) / m^3 digestate per year	1.92	1.72	2.25

I.3. Biogas Bree: NUTRICAS scenarios

I.3.1 Centrifuge + microfiltration + reverse osmosis + ion exchange

(GENIUS cascade GZV)

- Separation of the digestate by means of a centrifuge without addition of flocculants (polymers): already present at the plant of Biogas Bree.
- Further purifications of the liquid fraction by means of microfiltration and reverse osmosis.
- Ion exchange to create a permeate that is dischargeable in surface water.

Calculation model: "microfiltration + reverse osmosis + ion exchange"

	Liquid fraction vegetal digestate	Solids	Liquid fraction
After	Centrifuge	Microfiltration	
Mass (ton/year)	37,000	15,383	21,616
Total DM(%)	8.0	13.7	3.9
N total (g N /kg)	6.5	9.6	4.3
NH_4-N (g N/kg)	3.6	3.5	3.6
P total (g P/kg)	0.9	1.8	0.26
K total (g K/kg)	5.5	5.7	5.3

Dry matter content of liquid fraction after microfiltration is too high to enter the reverse osmosis units (red value). This should preferably be below 1.5-1% DM. To achieve this, dilution would be necessary (at least 1:3.5) or a liquid fraction of vegetal digestate with a DM content of around 4% instead of 8% by improved separation.

I.3.2 Liquid fraction acidification + evaporation + RO

(Nurmon Bioenergia and AM-Power scenario)

- Acidification of the liquid fraction after decanter centrifuge to make sure nitrogen remains in the evaporator concentrate after evaporation.
- Evaporation of the acidified liquid fraction.

Calculation model: Evaporation-condensation: "Evaporation at pH 7.8, 80°C"

	Liquid fraction vegetal digestate	Condensate	Concentrate
After	Centrifuge	Acidification + evaporation	
Mass (ton/year)	37,000	17,060	20,385
Total DM (%)	8	0.19	16.5
N total (g N /kg)	6.5	0.4	11.5
NH_4-N (g N/kg)	3.6	0.2	6.4
P total (g P/kg)	0.9	0.008	1.6
K total (g K/kg)	5.5	0.05	9.9

Acidification + Evaporation	most likely	minimum	maximum	Remarks
CAPEX (€)	1,050,000	800,000	1,500,000	
OPEX (€/year)	231,000	176,000	330,000	12% of CAPEX
H_2SO_4 96% (€/year)	57,187	408 Tonne/year		0.14 €/kg
antifoam (€/year)	118,400	37 Tonne/year		3.2 €/kg
Yearly cost (€/year)	476,587	404,921	605,587	CAPEX: 15 years de-preciation
Cost (€) / m³ liquid fraction per year	1.88	10.94	16.37	
Cost (€) / m³ digestate per year	11.08	9.42	14.08	

I.4 Waternet: NUTRICAS scenario

I.4.1 RePeat-acidification step on digestate

- No dilution of the digestaste of Waternet was needed, because of the high water content compared to solid fraction normally used in the original RePeat cascade.
- The digestate was acidified to pH 5 with H_2SO_4 96% fraction to transfer phosphorus from the fixed organic form to ortho-phosphate.
- Acidification tests have already been performed for Waternet's digested sludge (3% DM), indicating that only 3 mol H^+ was necessary per kg dry matter present in the digestate (Re-gelink et al. 2017) to reduce the pH to 5. This would be an amount of 4.6 kg H_2SO_4 96%/tonne digestate or 2.5 L H_2SO_4 96%/tonne digestate.

	Solid fraction	Acidified digestate
After	Digested sludge	RePeat acidification
Mass (ton/year)	650,000	652,990
pH	7.2	5
Total DM (%)	3.6	4.0
N total (g N /kg)	1.8	1.8
NH_4-N (g N/kg)	0.6	0.6
P total (g P/kg)	1.5	1.5
PO_4-P (g P/kg)	0.2	0.8
K total (g K/kg)	0.4	0.4

	No acidification	Acidification	Remarks
H_2SO_4 96%	0 L/tonne digestate 0 tonne/year	2.5 L/tonne digestate 2,990 tonne/year	
€/year	0	-4,007,500	-0.14€/kg
$MgCl_2$ 32%	PO_4-P= 0.2 g P/kg 2,364 tonne/year	PO_4-P= 0.8 g P/kg 8,152 tonne/year	Mg/P molar ratio 1.8 for stru-vite precipitation
€/year	-4,137,295	-14,265,394	-1.75€/kg
struvite	±600 tonne/year	±2,000 tonne/year	95% of PO_4-P recovered as struvite
€/year	+45,000	+150,000	±75 €/tonne struvite
Net cost per year chemicals and revenues struvite (€/year)	-4,092,295	-18,122,894	

I.5 GMB-BIR BV: NUTRICAS scenarios

I.5.1 Nitrogen stripping-scrubbing

Calculation model: "CO_2 stripping to pH 8.8, 65°C, 80% of NH_4-N stripped"

	Digestate	Ammonium sulphate solution	N stripped digestate
After		N stripping-scrubbing	
Mass (tonne/year)	21,000	1,008	20,219
Total DM (%)	5	1.0	6.2
N total (g N /kg)	4.5	61.7	1.6
NH_4-N (g N/kg)	3.7	61.7	0.8
P total (g P/kg)	0.7	0.001	0.7
K total (g K/kg)	5.1	0.01	5.3

Concentration AS solution: 235 g $(NH_4)_2SO_4$/ kg AS solution = 24% AS solution

N stripping-scrubbing	most likely	minimum	maximum	Remarks
CAPEX (€)	633,333	400,000	800,000	
OPEX (€/year)	25,967	16,400	32,800	4.10% of CAPEX
H_2SO_4 96% (€/year)	31,731	227 Tonne/year		0.14 €/kg
Yearly cost (€/year)	99,920	74,797	11,7864	CAPEX: 15 years depreciation
Cost (€) / m³ digestate per year	4,.8	3.6	5.6	

Marketing revenues for AS and N stripped digestate (total mass of 21,227 tonnes per year) should at on average 3.5 - 5.6 €/tonne product to be break even with the yearly CAPEX and OPEX.

I.6 Nurmon Bioenergia: NUTRICAS scenarios

I.6.1 Liquid fraction acidification + evaporation + RO

(Original Nurmon Bioenergia scenario)

- Acidification of the liquid fraction after decanter centrifuge to make sure nitrogen remains in the evaporator concentrate after evaporation.
- Evaporation of the acidified liquid fraction.
- The produced evaporator condensate is further purified in an RO installation, where the permeate can be discharged and the RO concentrate can be reused for cleaning purposes

Calculation model: Evaporation-condensation: "Evaporation at pH 7.8, 80°C"

	Liquid fraction	Condensate	Concentrate	RO concentrate	RO Permeate
After	Centrifuge	Evaporation		Reverse osmosis	
Mass (tonne/year)	185,000	152,355	34,873	47,909	106,478
Total DM (%)	3.6	0.46	23.3	5.0	0.24
N total (g N /kg)	5.5	0.19	28.1	0.6	0.012
NH_4-N (g N/kg)	4.9	0.15	25.4	0.5	0.011
P total (g P/kg)	0.4	0.003	2.1	0.01	0.0001
K total (g K/kg)	5.4	0.03	28.4	0.08	0.002

Acidification + Evaporation	Most likely	Minimum	Maximum	Remarks
CAPEX (€)	2,296,667	2,100,000	2,500,000	
OPEX (€/year)	275,600	252,000	300,000	12% of CAPEX
H_2SO_4 96% (€/year)	285,936	2042,4 Tonne/year		0.14 €/kg
antifoam (€/year)	592,000	185 Tonne/year		3.2 €/kg
Yearly cost (€/year)	1,306,647	1,269,936	1,344,603	CAPEX: 15 years depreciation
Cost (€) / m³ liquid fraction per year	7.06	6.86	7.27	
Cost (€) / m³ digestate per year	5.68	5.52	5.85	

Reverse osmosis + active carbon	Most likely	Minimum	Maximum	Remarks
CAPEX (€)	390,000	320,000	450,000	
OPEX (€/year)	7,800	6,400	9,000	2% of CAPEX
H_2SO_4 96% (€/year)	284,538	2,032 Tonne/year		Acidification membranes 0.14 €/kg
H_2SO_4 37% (€/year)	40,465	311 Tonne/year		For CIP 0.13 €/kg
Na(OH) 30% (€/year)	39,007	111 Tonne/year		For CIP 0.35 €/kg
Yearly cost (€/year)	397,809	391,742	403,009	CAPEX: 15 years depreciation
Cost (€) / m³ liquid fraction per year	2.15	2.12	2.18	
Cost (€) / m³ digestate per year	1.73	1.70	1.75	

Total cascade	Most likely	Minimum	Maximum
Yearly cost total cascade (€/year)	1,704,456	1,661,678	1,747,612
Cost (€) / m³ liquid fraction per year	9.21	8.98	9.45
Cost (€) / m³ digestate per year	7.41	7.22	7.60

I.6.2 N stripping-scrubbing + acidification + evaporator + RO

- Nitrogen stripping-scrubbing of the liquid fraction after decanter centrifuge.
- The N stripped digestate was acidified to make sure nitrogen remains in the evaporator concentrate after evaporation.
- The produced evaporator condensate is further purified in an RO installation, where the permeate can be discharged and the RO concentrate can be reused for cleaning purposes

Calculation model: N stripping-scrubbing: "CO_2 stripping to pH 8.8, 65°C, 80% of NH_4-N stripped"

Calculation model: Evaporation-condensation: "Evaporation at pH 7.8, 80°C"

	Liquid fraction	Ammonium sulphate solution	N stripped digestate	Condensate	Concentrate	RO concentrate	RO Permeate
After	Centrifuge	N stripping-scrubbing		Evaporation		Reverse osmosis	
Mass (tonne)	185,000	9,018	178,649	139,206	41,593	43,472	97,591
Total DM (%)	3.6	0.9	5.1	0.1	26.6	4.0	0.2
N total (g N /kg)	5.5	80.6	1.6	0.1	6.5	0.3	0.003
NH_4-N (g N/kg)	4.9	80.6	1.0	0.0	4.3	0.1	0.002
P total (g P/kg)	0.4	0.001	0.4	0.003	1.8	0.01	0.00004
K total (g K/kg)	5.4	0.01	5.6	0.03	23.8	0.09	0.002

N stripping-scrubbing	Most likely	Minimum	Maximum	Remarks
CAPEX (€)	6,250,000	1,500,000	15,000,000	
OPEX (€/year)	209,375	50,250	502,500	3.35% of CAPEX
Dilution water per year		17 Tonne/year		For AS
H_2SO_4 96% (€/year)	370,947	2,650 Tonne/year		0.14 €/kg
Yearly cost (€/year)	996,989	521,197	1,873,447	CAPEX: 15 years depreciation
Cost (€) / m^3 liquid fraction per year	5.4	2.8	10.1	
Cost (€) / m^3 digestate per year	4.3	2.3	8.1	

Acidification + evaporation	Most likely	Minimum	Maximum	Remarks
CAPEX (€)	2,297,500	2,100,000	2,500,000	
OPEX (€/year)	2,75,700	252,000	300,000	12% of CAPEX
H_2SO_4 96% (€/year)	276.119	1,972 Tonne/year		0.14 €/kg
antifoam (€/year)	571.676	179 Tonne/year		3.2 €/kg
Yearly cost (€/year)	1,276,662	1,239,795	1,314,462	CAPEX: 15 years depreciation
Cost (€) / m^3 liquid fraction per year	6.9	6.7	7.1	
Cost (€) / m^3 digestate per year	5.6	5.4	5.7	

Reverse osmosis + active carbon	Most likely	Minimum	Maximum	Remarks
CAPEX (€)	340,000	300,000	400,000	
OPEX (€/year)	6,800	6,000	8,000	2% of CAPEX
H_2SO_4 96% (€/year)	259,981	1,857 Tonne/year		Acidification membranes 0.14 €/kg
H_2SO_4 37% (€/year)	36,972	284 Tonne/year		For CIP 0.13 €/kg
Na(OH) 30% (€/year)	35,640	102 Tonne/year		For CIP 0.35 €/kg
Yearly cost (€/year)	362,061	358,594	367,261	CAPEX: 15 years depreciation
Cost (€) / m³ liquid fraction per year	2.0	1.9	2.0	
Cost (€) / m³ digestate per year	1.6	1.6	1.6	

Total cascade	Most likely	Minimum	Maximum
Yearly cost total cascade (€/year)	2,598,739	2,082,614	3,518,197
Cost (€) / m³ liquid fraction per year	14.2	11.5	19.2
Cost (€) / m³ digestate per year	11.5	9.2	15.5

I.6.3 Evaporation + N stripping-scrubbing + RO

- Evaporation of the liquid fraction after decanter centrifuge without prior acidification.
- The condensate of the evaporator (condensed ammonia water) is treated in N stripping-scrubbing installation.
- Afterwards the N stripped evaporator condensate is further purified in an RO installation, where the permeate can be discharged and the RO concentrate can be reused for cleaning purposes.

Calculation model: Evaporation: "Evaporation at pH 7.8, 80°C"

Calculation model: N stripping-scrubbing: "CO_2 stripping to pH 8.8, 65°C, 80% of NH_4-N stripped"

	Liquid fraction	Condensate	Concentrate	Ammonium sulphate solution	N stripped evaporator condensate	RO concentrate	RO Permeate
After	Centrifuge	Evaporation		N stripping-scrubbing		Reverse osmosis	
Mass (tonne/year)	185,000	146,288	38,897	7,337	141,070	45,217	97,735
Total DM (%)	3.6	0.03	17.5	0.3	1.5	7.7	0.4
N total (g N /kg)	5.5	5.0	7.1	79.24	1.08	3.21	0.08
NH_4-N (g N/kg)	4.9	5.0	4.7	79.23	1.03	3.05	0.07
P total (g P/kg)	0.40	0.003	1.9	0.00001	0.003	0.008	0.00004
K total (g K/kg)	5.4	0.03	25.5	0.0001	0.03	0.09	0.0022

Evaporation	Most likely	Minimum	Maximum	Remarks
CAPEX (€)	2,296,667	2,100,000	2,500,000	
OPEX (€/year)	275,600	252,000	300,000	12% of CAPEX
H_2SO_4 96% (€/year)		0 tonne/year		0.14 €/kg
antifoam (€/year)	592000	185	Ton	3.2 €/kg
Yearly cost (€/year)	1,020,711	984,000	1058,667	CAPEX: 15 years depreciation
Cost (€) / m^3 liquid fraction per year	5.52	5.32	5.72	
Cost (€) / m^3 digestate per year	4.44	4.28	4.60	

N stripping-scrubbing	Most likely	Minimum	Maximum	Remarks
CAPEX (€)	581,083	250,000	668,250	
OPEX (€/year)	19,466	8,375	22,386	3,35% of CAPEX
H_2SO_4 96% (€/year)	296,758	2,119 tonne/year		0,14€/kg
Yearly cost (€/year)	354,963	321,799	363,694	CAPEX: 15 years depreciation
Cost (€) / m^3 liquid fraction per year	1.92	1.74	1.97	
Cost (€) / m^3 digestate per year	1.54	1.40	1.58	

Reverse osmosis + active carbon	Most likely	Minimum	Maximum	Remarks
CAPEX (€)	60,000	52,500	70,000	
OPEX (€/year)	1,200	1050	1,400	2% of CAPEX
H_2SO_4 96% (€/year)	263,463	1881 tonne/year		Acidification membranes 0.14 €/kg
H_2SO_4 37% (€/year)	37,468	288 tonne/year		For CIP 0.13 €/kg
Na(OH) 30% (€/year)	36,117	103 tonne/year		For CIP 0.35 €/kg
Yearly cost (€/year)	342,248	341,598	343,114	CAPEX: 15 years depreciation
Cost (€) / m^3 liquid fraction per year	1.85	1.85	1.85	
Cost (€) / m^3 digestate per year	1.49	1.49	1.49	

Total cascade	Most likely	Minimum	Maximum
Yearly cost total cascade (€/year)	1,151,821	1,081,297	1,199,375
Cost (€) / m^3 liquid fraction per year	9.29	8.90	9.54
Cost (€) / m^3 digestate per year	7.47	7.16	7.68

I.6.4 RePeat cascade on solid fraction

- A 1:4 dilution of solid fraction after decanter centrifuge, acidification to pH 5 with H_2SO_4 96% fraction to transfer phosphorus from the fixed organic form to ortho-phosphate.
- Separation of acidified solid fraction with 2 screw presses to produce a P low organic soil improver and $Ca(SO_4)_2$ sludge removal with lamella separator.
- Basification of liquid fraction to pH8 with $Ca(OH)_2$ 45%.
- Precipitation Ca-P salts sludge.
- Additional cleaning steps to remove organic matter and digestate residues and additional drying of Ca-P salts are not included in the simulation.
- All other liquid streams are recycled in the process.

	Solid fraction	Low-P soil improver	$Ca(SO_4)_2$ sludge	Ca-P salts sludge
After	Centrifuge	RePeat		
Mass (tonne)	43,000	31,251	16,186	21,917
Total DM (%)	29.0	28.5	6.7	15.9
N total (g N /kg)	12.5	6.4	4.7	7.7
NH_4-N (g N/kg)	6.4	1.2	2.9	4.8
P total (g P/kg)	9.7	1.4	3.4	12.0
K total (g K/kg)	4.1	1.4	2.4	1.7

RePeat	Most likely	Minimum	Maximum	Remarks
CAPEX (€)	900000	700000	1200000	
OPEX (€/year)	45000	35000	60000	5% of CAPEX
Dilution water		129000 Tonne/year		
H_2SO_4 96% (€/year)	243690	1741 Tonne/year		
$Ca(OH)_2$ 45% (€/year)	154856	1290 Tonne/year		
Yearly cost (€/year)	503545	480212	538545	CAPEX: 15 years depreciation
Cost (€) / m³ solid fraction per year	11,7	11,2	12,5	
Cost (€) / m³ digestate per year	2,2	2,1	2,3	

I.7 Gasum - Götene: NUTRICAS scenarios

I.7.1 Nitrogen stripping-scrubbing

On raw digestate

Calculation model: "CO_2 stripping to pH 8.8, 65°C, 80% of NH_4-N stripped"

	Digestate	Ammonium sulphate solution	N stripped digestate
After		N stripping-scrubbing	
Mass (tonne/year)	380,000	17,300	366,469
Total DM (%)	10.8	2.0	12.1
N total (g N /kg)	6.4	59.8	3.8
NH_4-N (g N/kg)	3.4	59.7	0.7
P total (g P/kg)	1.2	0.002	1.2
K total (g K/kg)	3.7	0.01	3.8

Concentration AS solution: 282 g $(NH_4)_2SO_4$/ kg AS solution = 28% AS solution

N stripping-scrubbing	Most likely	Minimum	Maximum	Remarks
CAPEX (€)	7,833,333	3,500,000	15,000,000	
OPEX (€/year)	250,667	112,000	480,000	3.2% of CAPEX
H_2SO_4 96% (€/year)	527,620	3,769 tonne/year		0.14 €/kg
Yearly cost (€/year)	1,300,509	872,954	2007620	CAPEX: 15 years depreciation
Cost (€) / m³ digestate per year	3.4	2.3	5.3	

Marketing revenues for AS and N stripped digestate (total mass of 38,3769 tonnes per year) should at on average 2.3 - 5.2 €/tonne product to be break even with the yearly CAPEX and OPEX.

On liquid fraction

Calculation model: N stripping-scrubbing: "CO_2 stripping to pH 8.8, 65°C, 80% of NH_4-N stripped"

	Liquid fraction	Ammonium sulphate solution	N stripped digestate
After	Centrifuge	N stripping-scrubbing	
Mass (tonne)	339,000	15,852	326,609
Total DM (%)	7.9	1.5	9.1
N total (g N /kg)	6.1	59.9	3.4
NH_4-N (g N/kg)	3.5	59.9	0.7
P total (g P/kg)	0.9	0.001	0.9
K total (g K/kg)	2.9	0.01	3.0

Concentration AS solution: 282 g $(NH_4)_2SO_4$/ kg AS solution = 28% AS solution

N stripping-scrubbing	Most likely	Minimum	Maximum	Remarks
CAPEX (€)	7,833,333	3500000	15,000,000	
OPEX (€/year)	250,667	112000	480,000	3.35% of CAPEX
H_2SO_4 96% (€/year)	484,537	3,461 tonne/year		0.14 €/kg
Yearly cost (€/year)	1,257,426	829,870	1,964,537	CAPEX: 15 years depreciation
Cost (€) / m³ liquid fraction per year	3.7	2.4	5.8	
Cost (€) / m³ digestate per year	3.3	2.2	5.2	

Marketing revenues for AS and N stripped digestate (total mass of 34,2461 tonnes per year) should at on average 2.4 - 5.7 €/tonne product to be break even with the yearly CAPEX and OPEX.

I.7.2 Fiberplus N stripping-scrubbing

Calculation model: "CO_2 stripping to pH 7.8, 80°C, 80% of NH_4-N stripped (excluding fiber extraction and paper making)

	Digestate	FGD Gypsum 73%	N stripped digestate	Ammonium sulphate solution	Calcium carbonate
After			Fiberplus N stripping-scrubbing		
Mass (tonne/year)	380,000	8,748	355,007	17,234	16,507
Total DM (%)	10.8	75	8.7	20.8	79.3
N total (g N /kg)	6.4	0.3	3.8	48.1	14.6
NH_4-N (g N/kg)	3.4	0.1	0.7	48.0	12.5
P total (g P/kg)	1.2	0.1	1.3	0.003	0.135
K total (g K/kg)	3.7	0.2	3.9	0.002	0.36

Concentration AS solution: 226 g $(NH_4)_2SO_4$/ kg AS solution = 22.6 % AS solution

Fiberplus N stripping-scrubbing	Most likely	Minimum	Maximum	Remarks
CAPEX (€)	3,250,000	2,000,000	4,500,000	
OPEX (€/year)	100,750	62,000	139,500	3.1% of CAPEX
FGD Gypsum 73% (€/year)	104,980	8,748 tonne/year		0.012 €/kg
Yearly cost (€/year)	422,397	300,313	544,480	CAPEX: 15 years depreciation
Cost (€) / m³ digestate per year	1.1	0.8	1.4	

Marketing revenues for $CaCO_3$, AS and N stripped digestate should at on average 0.8 - 1.4 €/tonne product to be break even with the yearly CAPEX and OPEX.

I.7.3 RePeat on solid fraction

- A 1:4 dilution of solid fraction after decanter centrifuge, acidification to pH 5 with H_2SO_4 96% fraction to transfer phosphorus from the fixed organic form to ortho-phosphate.
- Separation of acidified solid fraction with 2 screw presses to produce a P low organic soil improver and $Ca(SO_4)_2$ sludge removal with lamella separator.
- Basification of liquid fraction to pH8 with $Ca(OH)_2$ 45%.
- Precipitation Ca-P salts sludge.
- Additional cleaning steps to remove organic matter and digestate residues and additional drying of Ca-P salts are not included in the simulation.
- All other liquid streams are recycled in the process.

	Solid fraction	Low-P soil improver	$Ca(SO_4)_2$ sludge	Ca-P salts sludge
After	Centrifuge	RePeat		
Mass (tonne)	41,000	31,057	15,381	21,133
Total DM (%)	35.0	32.5	7.9	18.2
N total (g N /kg)	8.9	5.3	3.0	5.1
NH_4-N (g N/kg)	3.0	0.6	1.4	2.2
P total (g P/kg)	3.8	0.5	1.2	4.8
K total (g K/kg)	10.0	3.3	5.9	4.2

RePeat	Most likely	Minimum	Maximum	Remarks
CAPEX (€)	900,000	700,000	1,200,000	
OPEX (€/year)	45,000	35,000	60,000	5% of CAPEX
Dilution water		123,000 tonne/year		
H_2SO_4 96% (€/year)	232,355	1,660 tonne/year		0.14€/kg
$Ca(OH)_2$ 45% (€/year)	147,653	1,230 tonne/year		0.12€/kg
Yearly cost (€/year)	485,008	461,675	520008	CAPEX: 15 years depreciation
Cost (€) / m³ solid fraction per year	11.8	11.3	12.7	
Cost (€) / m³ digestate per year	1.28	1.21	1.37	

Marketing revenues for Low P soil improver, $Ca(SO_4)_2$ sludge and Ca-P salts sludge should at on average 7.7 – 8.7 €/tonne product to be break even with the yearly CAPEX and OPEX for solid fraction processing in the RePeat installation.

I.7.4 Liquid fraction acidification + evaporation + RO

(Nurmon Bioenergia and AM-Power scenario)

On liquid fraction

- Acidification of the liquid fraction after decanter centrifuge to make sure nitrogen remains in the evaporator concentrate after evaporation.
- Evaporation of the acidified liquid fraction.
- The produced evaporator condensate is further purified in an RO installation, where the permeate can be discharged and the RO concentrate can be reused for cleaning purposes.

Calculation model: evaporation-condensation:"Evaporation at pH 7.8, 80°C".

	Liquid fraction	Condensate	Concentrate	Concentrate	Permeate
After	Centrifuge	Evaporation		Reverse osmosis	
Mass (tonne/year)	339,000	230,817	112,264	107,424	126,472
Total DM (%)	7.9	0.80	25.7	4.0	0.4
N total (g N/kg)	6.1	0.3	17.9	0.6	0.02
NH_4-N (g N/kg)	3.5	0.1	10.3	0.3	0.01
P total (g P/kg)	0.9	0.007	2.7	0.01	0.0002
K total (g K/kg)	2.9	0.02	8.7	0.04	0.002

Acidification + Evaporation	Most likely	Minimum	Maximum	Remarks
CAPEX (€)	3,000,000	2,500,000	3,500,000	
OPEX (€/year)	360,000	300,000	420,000	12% of CAPEX
H_2SO_4 96% (€/year)	523,958	3,743 tonne/year		0.14 €/kg
antifoam (€/year)	1,084,800	339 tonne/year		3.2 €/kg
Yearly cost (€/year)	2,168,758	2,075,425	2262092	CAPEX: 15 years depreciation
Cost (€) / m³ liquid fraction per year	6.40	6.12	6.67	
Cost (€) / m³ digestate per year	5.71	5.46	5.95	

Reverse osmosis + active carbon	Most likely	Minimum	Maximum	Remarks
CAPEX (€)	560,000	550,000	570,000	
OPEX (€/year)	11,200	11,000	11,400	2% of CAPEX
H_2SO_4 96% (€/year)	431,074	3,079 tonne/year		Acidification membranes 0.14 €/kg
H_2SO_4 37% (€/year)	61,304	472 tonne/year		For CIP 0.13 €/kg
Na(OH) 30% (€/year)	59,095	169 tonne/year		For CIP 0.35 €/kg
Yearly cost (€/year)	600007	599140	600873	CAPEX: 15 years deprecia-tion
Cost (€) / m^3 liquid fraction per year	1.770	1.767	1.772	
Cost (€) / m^3 digestate per year	1.579	1.577	1.581	

Total cascade	Most likely	Minimum	Maximum
Yearly cost (€/year)	2,768,765	2,674,565	2,862,965
Cost (€) / m^3 liquid fraction per year	8.2	7.9	8.4
Cost (€) / m^3 digestate per year	7.3	7.0	7.5

I.8 Biomeco AD: NUTRICAS scenarios

I.8.1 Centrifuge (no additives) + microfiltration + reverse osmosis + ion exchange

Digestate with dry matter content of 7%

- Separation of the 128 ktonne of digestate per year by means of a centrifuge without addition of flocculants (polymers) would produce a liquid fraction with a dry matter content between 3-5%.
- Further purifications of 50% of the liquid fraction by means of microfiltration and reverse osmosis.
- Ion exchange to create a permeate that is dischargeable in surface water.

Product	Best case Digestate	Solid fraction	Liquid frac-tion	Solids	Liquid frac-tion
After		Decanter centrifuge		Microfiltration	
Mass (tonne/year)	128,000	15,360	50% 112,640 tonne = 56,320	22,509	33,811
Total DM(%)	7.0	35.9	3.0	5.3	1.4
N total (g N /kg)	4.8	7.4	4.6	6.1	3.6
NH_4-N (g N/kg)	3.2	2.3	3.3	3.4	3.2
P total (g P/kg)	0.4	1.4	0.2	0.3	0.03
K total (g K/kg)	5.1	4.6	4.8	5.1	4.6

A liquid fraction after the centrifuge has to have maximum 3%DM to be able to achieve a quality of 1-1.5% DM before entering the RO (green value).

Product	Concentrate	Permeate	Spent regenerant solution	Purified water
after	Reverse osmosis		Ion exchange	
Mass (ton/year)	15,769	18,492	1,995	18,346
Total DM(%)	4.8	0.8	7.3	0.01
N total (g N /kg)	7.0	0.6	5.5	0.0004
NH_4-N (g N/kg)	6.2	0.6	5.4	0.0003
P total (g P/kg)	0.07	0.0009	0.008	0.00004
K total (g K/kg)	9.4	0.4	3.7	0.0001

Centrifuge	Most likely	Minimum	Maximum	Remarks
CAPEX (€)	135,000	100,000	150,000	
OPEX (€/year)	6,750	5,000	7,500	5% of CAPEX
Yearly cost (€/year)	20,250	15,000	22,500	CAPEX: 10 years depreciation
Cost (€) / m³ digestate per year	0.16	0.12	0.18	

Microfiltration	Most likely	Minimum	Maximum	Remarks
CAPEX (€)	330,000	260,000	400,000	
OPEX (€/year)	16,500	13,000	20,000	5% of CAPEX
Yearly cost (€/year)	38,500	30,333	46,667	CAPEX: 15 years depreciation
Cost (€) / m³ liquid fraction processed per year	0.68	0.54	0.83	
Cost (€) / m³ digestate per year	0.30	0.24	0.36	

Reverse osmosis	Most likely	Minimum	Maximum	Remarks
CAPEX (€)	241,000	120,000	440,000	
OPEX (€/year)	9,640	4,800	17,600	4% of CAPEX
H_2SO_4 96% (€/year)	63,145	451 Tonne/year		Acidification membranes 0.14 €/kg
H_2SO_4 37% (€/year)	8,980	69 Tonne/year		For CIP 0.13 €/kg
Na(OH) 30% (€/year)	8,656	25 Tonne/year		For CIP 0.35 €/kg
Yearly cost (€/year)	106,489	93,582	127,715	CAPEX: 15 years depreciation
Cost (€) / m³ liquid fraction per year	1.89	1.66	2.27	
Cost (€) / m³ digestate per year	0.83	0.73	1.00	

Ion exchange	Most likely	Minimum	Maximum	Remarks
CAPEX (€)	8,750	7,000	10,500	
OPEX (€/year)	88	70	105	1% of CAPEX
Flushing water		1,849 Tonne/year		
H_2SO_4 96% (€/year)	48	0.3 Tonne/year		For regeneration IE 0,14 €/kg
Na(OH) 50% (€/year)	224	0.6 Tonne/year		For regeneration IE 0,4 €/kg
Yearly cost (€/year)	943	808	1,077	CAPEX: 15 years depre-ciation
Cost (€) / m³ liquid fraction per year	0.017	0.014	0.019	
Cost (€) / m³ digestate per year	0.007	0.006	0.008	

Total cascade Centrifuge + MF + RO + IE	Most likely	Minimum	Maximum
Yearly cost (€/year)	166,181	139,724	197,959
Cost (€) / m³ digestate per year (incl. centrifuge)	1.30	1.09	1.55
Total cascade MF + RO + IE	**Most likely**	**Minimum**	**Maximum**
Yearly cost (€/year)	145,931	124,724	175,459
Cost (€) / m³ liquid fraction processed per year	2.59	2.21	3.12

Digestate with dry matter content of 9%

Product	Worst case digestate	Liquid fraction	Solids	Liquid fraction
After		Decanter centrifuge	Microfiltration	
Mass (ton/year)	128,000	112640 50%= 56,320	22,944	33,376
Total DM(%)	9.0	5.3	9.4	2.6
N total (g N /kg)	5.0	4.7	6.1	3.7
NH_4-N (g N/kg)	3.2	3.3	3.4	3.3
P total (g P/kg)	0.3	0.2	0.3	0.04
K total (g K/kg)	4.9	4.9	5.1	4.7

If the Liquid fraction after the centrifuge has a DM content of 5%DM it will not be able to achieve a quality of 1-1.5% DM before entering the RO (red value).

Dilution of LF fraction after centrifuge

Product	Worst case digestate	Liquid fraction	Liquid fraction diluted 1:0.7	Solids	Liquid fraction
After		Decanter centrifuge		Microfiltration	
Mass (tonne/year)	128,000	50% of 112,640 tonne 56,320	56,320 tonne + 39,424 tonne water = 95,744 ton	38,320	57,424
Total DM(%)	9.0	5.3	1.5	5.6	1.5
N total (g N /kg)	5.0	4.7	2.1	3.7	2.1
NH_4-N (g N/kg)	3.2	3.3	1.9	2.0	1.9
P total (g P/kg)	0.3	0.2	0.0	0.2	0.02
K total (g K/kg)	4.9	4.9	2.8	3.0	2.8

Centrifuge	Most likely	Minimum	Maximum	Remarks
CAPEX (€)	135,000	100,000	150,000	
OPEX (€/year)	6,750	5,000	7,500	5% of CAPEX
Yearly cost (€/year)	20,250	15,000	22,500	CAPEX: 10 years depreciation
Cost (€) / m³ digestate per year	0.16	0.12	0.18	

Microfiltration	Most likely	Minimum	Maximum	Remarks
CAPEX (€)	330,000	260,000	400,000	
OPEX (€/year)	16,500	13,000	20,000	5% of CAPEX
Yearly cost (€/year)	38,500	30,333	46,667	CAPEX: 15 years depreciation
Cost (€) / m³ liquid fraction processed per year	0.68	0.54	0.83	
Cost (€) / m³ digestate per year	0.30	0.24	0.36	

Reverse osmosis	Most likely	Minimum	Maximum	Remarks
CAPEX (€)	241,000	120,000	440,000	
OPEX (€/year)	9,640	4,800	17,600	4% of CAPEX
H_2SO_4 96% (€/year)	107,246	766 tonne/year		Acidification membranes 0.14 €/kg
H_2SO_4 37% (€/year)	15,252	117 tonne/year		For CIP 0.13 €/kg
Na(OH) 30% (€/year)	14,702	42 tonne/year		For CIP 0.35 €/kg
Yearly cost (€/year)	162,906	149,999	184,133	CAPEX: 15 years depreciation
Cost (€) / m³ liquid fraction per year	2.89	2.66	3.27	
Cost (€) / m³ digestate per year	1.27	1.17	1.44	

Ion exchange	Most likely	Minimum	Maximum	Remarks
CAPEX (€)	8,750	7,000	10,500	
OPEX (€/year)	88	70	105	1% of CAPEX
Flushing water		3,138 tonne/year		
H_2SO_4 96% (€/year)	81	0,6 tonne/year		For regeneration IE 0.14 €/kg
Na(OH) 50% (€/year)	380	1,0 tonne/year		For regeneration IE 0.4 €/kg
Yearly cost (€/year)	1,132	998	1,266	CAPEX: 15 years depreciation
Cost (€) / m³ liquid fraction per year	0.020	0.018	0.022	
Cost (€) / m³ digestate per year	0.009	0.008	0.010	

Total cascade Centrifuge + MF + RO + IE	Most likely	Minimum	Maximum
Yearly cost (€/year)	222,788	196,331	254,566
Cost (€) / m³ digestate per year	1.74	1.53	1.99
Total cascade MF + RO + IE	**Most likely**	**Minimum**	**Maximum**
Yearly cost (€/year)	202,538	181,331	232,066
Cost (€) / m³ liquid fraction processed per year	3.60	3.22	4.12

I.8.2 Centrifuge (+ additive) + microfiltration + reverse osmosis + ion exchange

- Separation of the 128 ktonne of digestate per year by means of a centrifuge with addition of flocculants (polymers).
- Further purifications of 50% of the liquid fraction by means of microfiltration and reverse osmosis.
- Ion exchange to create a permeate that is dischargeable in surface water.

Product	Digestate	Solid fraction	Liquid fraction	Solids	Liquid fraction
After		Decanter centrifuge		Microfiltration	
Mass (ton/year)	128,000	15,488	50% of 125,312 tonne = 62,656	25,092	37,564
Total DM(%)	6.0	24.6	3.1	5.7	1.4
N total (g N /kg)	5.0	10.4	3.8	4.8	3.1
NH_4-N (g N/kg)	3.2	2.6	3.0	3.0	2.9
P total (g P/kg)	0.3	1.9	0.1	0.2	0.02
K total (g K/kg)	4.9	5.3	4.3	4.5	4.1

Product	Concentrate	Permeate	Spent regenerant solution	Purified water
After	Reverse osmosis		Ion exchange	
Mass (tonne/year)	17,527	20,537	2,217	20,374
Total DM(%)	4.9	0.8	7.4	0.01
N total (g N /kg)	6.1	0.5	5.0	0.0003
NH_4-N (g N/kg)	5.6	0.5	4.9	0.0003
P total (g P/kg)	0.05	0.0007	0.006	0.00003
K total (g K/kg)	8.5	0.4	3.3	0.0001

Centrifuge	Most likely	Mminimum	Maximum	Remarks
CAPEX (€)	135,000	100,000	150,000	
OPEX (€/year)	6,750	5,000	7,500	5% of CAPEX
Powder polymer	192,000	64 Tonne/year		0.5% solution in water Addition of 100L/m³ digestate
Yearly cost (€/year)	212,250	207,000	214,500	CAPEX: 10 years depreciation
Cost (€) / m³ digestate per year	1.66	1.62	1.68	

Microfiltration	Most likely	Minimum	Maximum	Remarks
CAPEX (€)	330,000	260,000	400,000	
OPEX (€/year)	16,500	13,000	20,000	5% of CAPEX
Yearly cost (€/year)	38,500	30,333	46,667	CAPEX: 15 years depreciation
Cost (€) / m³ liquid fraction processed per year	0.61	0.48	0.74	
Cost (€) / m³ digestate per year	0.30	0.24	0.36	

Reverse osmosis	Most likely	Minimum	Maximum	Remarks
CAPEX (€)	241,000	120,000	440,000	
OPEX (€/year)	9,640	4,800	17,600	4% of CAPEX
H_2SO_4 96% (€/year)	70,154	501 Tonne/year		Acidification membranes 0,14 €/kg
H_2SO_4 37% (€/year)	9,977	77 Tonne/year		For CIP 0,13 €/kg
Na(OH) 30% (€/year)	9,617	27 Tonne/year		For CIP 0,35 €/kg
Yearly cost (€/year)	115,455	102,548	136,681	CAPEX: 15 years depreciation
Cost (€) / m³ liquid fraction per year	1.84	1.64	2.18	
Cost (€) / m³ digestate per year	0.90	0.80	1.07	

Ion exchange	Most likely	Minimum	Maximum	Remarks
CAPEX (€)	8,750	7,000	10,500	
OPEX (€/year)	88	70	105	1% of CAPEX
Flushing water		2,053 Tonne/year		
H_2SO_4 96% (€/year)	53	0.4 Tonne/year		For regeneration IE 0,14 €/kg
Na(OH) 50% (€/year)	249	0.6 Tonne/year		For regeneration IE 0,4 €/kg
Yearly cost (€/year)	973	838	1,107	CAPEX: 15 years depreciation
Cost (€) / m³ liquid fraction per year	0.016	0.013	0.018	
Cost (€) / m³ digestate per year	0.008	0.007	0.009	

Total cascade Centrifuge (+additives) + MF + RO + IE	Most likely	Minimum	Maximum
Yearly cost (€/year)	367,177	340,720	398,955
Cost (€) / m³ digestate per year	2.87	2.66	3.12
Total cascade MF + RO + IE	**Most likely**	**Minimum**	**Maximum**
Yearly cost (€/year)	154,927	133,720	184,455
Cost (€) / m³ liquid fraction processed per year	2.47	2.13	2.94

I.8.3 Centrifuge (no additives) + DAF + microfiltration + reverse osmosis + ion exchange

Digestate with dry matter content of 9%

- Separation of the 128 ktonne of digestate per year by means of a centrifuge without addition of flocculants (polymers).
- 50% of the liquid fraction undergoes and extra removal of suspended solids by means of a dissolved air flotation (DAF).
- Further purification of the liquid fraction of the DAF by means of microfiltration and reverse osmosis.
- Ion exchange to create a permeate that is dischargeable in surface water.

Product	Worst case digestate	Solid fraction	Liquid fraction	Flotation sludge	Liquid fraction
After		Decanter centrifuge		Dissolved Air Flotation	
Mass (ton/year)	128,000	15,360	112,640 50%= 56,320	11,489	45,957
Total DM(%)	9.0	35.9	5.3	19.1	1.8
N total (g N /kg)	5.0	7.4	4.7	4.9	4.5
NH_4-N (g N/kg)	3.2	2.3	3.3	2.8	3.4
P total (g P/kg)	0.3	1.4	0.2	0.36	0.10
K total (g K/kg)	4.9	4.6	4.9	4.50	4.85

Product	Solids	Liquid fraction	Concen-trate	Permeate	Spent re-generant solution	Purified water
After	Microfiltration		Reverse osmosis		Ion exchange	
Mass (tonne/year)	18,062	27,895	12,991	15,276	1,649	15,155
Total DM(%)	2.5	1.3	4.6	0.8	7.4	0.01
N total (g N /kg)	5.9	3.6	7.1	0.6	5.6	0.0004
NH_4-N (g N/kg)	3.5	3.3	6.3	0.6	5.5	0.0003
P total (g P/kg)	0.2	0.03	0.06	0.0008	0.007	0.00004
K total (g K/kg)	5.2	4.6	9.5	0.4	3.7	0.0001

Centrifuge	Most likely	Minimum	Maximum	Remarks
CAPEX (€)	135,000	100,000	150,000	
OPEX (€/year)	6,750	5,000	7,500	5% of CAPEX
Yearly cost (€/year)	20,250	15,000	22,500	CAPEX: 10 years de-preciation
Cost (€) / m^3 digestate per year	0.16	0.12	0.18	

Dissolved Air Flotation	Most likely	Minimum	Maximum	Remarks
CAPEX (€)	205,380	35,000	375,760	
OPEX (€/year)	6,161	1,050	11,273	3% of CAPEX
Powder polymer	16,896	5,632 Tonne/year		0.5% solution in water Addition of 20 L/m^3 LF
Yearly cost (€/year)	43,595	21,446	65,745	CAPEX: 10 years de-preciation
Cost (€) / m^3 liquid fraction processed per year	0.77	0.38	1.17	
Cost (€) / m^3 digestate per year	0.34	0.17	0.51	

Microfiltration	Most likely	Minimum	Maximum	Remarks
CAPEX (€)	330,000	260,000	400,000	
OPEX (€/year)	16,500	13,000	20,000	5% of CAPEX
Yearly cost (€/year)	38,500	30,333	46,667	CAPEX: 15 years de-preciation
Cost (€) / m^3 liquid fraction processed per year	0.68	0.54	0.83	
Cost (€) / m^3 digestate per year	0.30	0.24	0.36	

Reverse osmosis	Most likely	Minimum	Maximum	Remarks
CAPEX (€)	241,000	120,000	440,000	
OPEX (€/year)	9,640	4,800	17,600	4% of CAPEX
H_2SO_4 96% (€/year)	52,097	372 Tonne/year		Acidification membranes 0,14 €/kg
H_2SO_4 37% (€/year)	7,409	57 Tonne/year		For CIP 0,13 €/kg
Na(OH) 30% (€/year)	7,142	20 Tonne/year		For CIP 0,35 €/kg
Yearly cost (€/year)	92,354	79,448	113,581	CAPEX: 15 years depre-ciation
Cost (€) / m³ liquid fraction per year	1.64	1.41	2.02	
Cost (€) / m³ digestate per year	0.72	0.62	0.89	

Ion exchange	Most likely	Minimum	Maximum	Remarks
CAPEX (€)	8,750	7,000	10,500	
OPEX (€/year)	88	70	105	1% of CAPEX
Flushing water		1,849 Tonne/year		
H_2SO_4 96% (€/year)	39	0,3 Tonne/year		For regeneration IE 0.14 €/kg
Na(OH) 50% (€/year)	185	0,5 Tonne/year		For regeneration IE 0.4 €/kg
Yearly cost (€/year)	895	761	1,029	CAPEX: 15 years depre-ciation
Cost (€) / m³ liquid fraction per year	0.02	0.01	0.02	
Cost (€) / m³ digestate per year	0.007	0.006	0.008	

Total cascade Centrifuge + MF + RO + IE	Most likely	Minimum	Maximum
Yearly cost (€/year)	195,595	146,988	249,522
Cost (€) / m³ digestate per year	1.53	1.15	1.95
Total cascade MF + RO + IE	**Most likely**	**Minimum**	**Maximum**
Yearly cost (€/year)	175,345	131,988	227,022
Cost (€) / m³ liquid fraction processed per year	3.11	2.34	4.03

II. ANNEX II – Detailed description of companies that are no longer involved as Outreach Location

Here the factseets of companies Greengas AD, Biogas Makassar and Emeraude BioEnergie and RIKA Bio-Tech are presented for additional detailed information.

II.1 RIKA Biotech – DVO (United Kingdom)

II.1.1 Description of the company

Rika Biotech is a developer of European Anaerobic Digestion (AD) projects. Rika is developing a pipeline of large volume manure and agri-waste projects in the UK, Holland, Belgium and Greece.

The Rika model is to develop, own and operate energy from waste projects, specifically AD. Working with local development partners, it takes projects from feedstock and site identification, through to planning, permitting, financing, construction and commissioning. It secures all feedstock and off-take contracts and selects proven, bankable contractors for project construction and O&M provision.

Rika is to implement a leading US biogas and nutrient recovery technology by DVO, uniquely suited to large volumes of waste material high nitrate containing material such as chicken manure. The DVO technology is successfully implemented at several farms in the USA and RIKA has designed projects for large chicken farms in Kent (UK) i.e. **"Fridays",** Wijster (NL) and Gent (BE) utilising the DVO technology.

II.1.2 Business environment

Mostly these farms are located in regions or hotspots with (local) manure surpluses where digestate is hard to dispose of in a cost-effective way. Many biogas plants find it challenging to dispose of digestate let alone create a market value for digestate. DVO plats in the US have managed to sell digestate in the retail market under the trade name Magic Dirt (www.magic-dirt.com)

Renewable fertilisers should be accounted for in manure and/or nutrient management planning to achieve good crop performance and to avoid environmental harm. The Fertiliser Manual (RB209) and SRUC Technical Note TN650 provide detailed information. Compost and fibre digestate can be spread with most conventional muck spreaders, while whole and liquor digestates are best applied with precision application equipment such as a band spreader, either trailing hose or trailing shoe, or shallow injector, to minimise ammonia emissions and maximise crop available nitrogen. If food wastes or other permitted animal by-products are processed through composting or AD systems, pasteurisation or sanitisation phases are required by law.

Phosphorus limits

Specific Environment Agency authorisations are generally not required in the UK when certified material is used – such as PAS110- although legal restrictions still apply where renewable fertilisers are derived from food waste and other animal by-products.

Since the digestate and the derived products will be produced out of poultry manure, they would still be considered as an animal manure and not a mineral fertiliser according to the EU Nitrates Directive, which means that the legislative rules of the Nitrates Directive have also to be taken into account.

Nitrogen limits

Since the digestate and the derived products will be produced out of poultry manure, they would still be considered as an animal manure and not a mineral fertiliser according to the Nitrates Directive, which means that the legislative rules of the Nitrates Directive have to be taken into account.

Nutrient demand

By removing 50,000 tonnes of poultry manure form the local market the project is expected to actually create a market for digestate. Being close to London the market for solid organic fertilisers is saturated due to availability of huge quantities of post digested sewage sludge.

II.1.3 Business case evolution during SYSTEMIC

RIKA Biotech has designed a anaerobic digestion concept for a chicken farms. An example is given for a system digesting 55,000 tonnes of poultry manure and straw per year.

Feedstocks

Table 6-1 Origin of feedstock of Fridays in Kent, UK (estimation for when plant will be operational)

Type	Mass (ktonne /year)
Poultry manure	55
Straw	2.5
Total	57.5

Biogas production

Anaerobic digestion in conjunction with CHP (Electricity Capacity: up to 500 kW and Thermal Energy Capacity: up to 500 kW) and biomethane production (up to 6 MW) for injection into the local gas network.

Installed electric capacity (IEC)	**1.8 MW**
Installed biomethane capacity	450 m^3
Digester volume	16,000 m^3
Annual biogas output / biogas per t of feedstock	7.2 Mm^3 / 125 m^3/t
Annual electricity net-output (fed to the grid)	3,750 MWh (4,125 MWh_{heat})
Annual bio-methane output	2.8 Mm^3

Digestate treatment cascade

The ultimate goal of this AD plant would be to generate value from manure via anaerobic digestion and provide solutions to farmers whose manure is a liability to their business rather than an asset.

The anaerobic digester works as a mixed plug-flow digester under mesophilic conditions and will be equipped with an inline NH_3 stripping-scrubbing unit to prevent NH_3 toxification of the digester. According to Rika, this will improve the efficiency of the anaerobic digestion phase by reducing the requirement for water to dilute high nitrogen containing feedstocks (e.g. poultry manure).

DVO digesters are built underground, taking advantage of the earth's natural insulating properties to keep microorganisms functioning at their highest levels of efficiency. Since the digester is built in the ground, the surrounding land acts like a berm for the digester and reduces the risk for waste spill or leakage. However, a disadvantage is that leakages could also happen unnoticed, and that maintenance works might be more difficult.

Most digesters use one of two conventional technologies – either the mixed or plug flow process. DVO's Two-Stage Mixed Plug Flow technology combines the mixed and plug flow processes into one solution. The system continually mixes a wide range of solids at a carefully controlled temperature, using a first-in, first-out design that guarantees retention time to maximize waste digestion.

DVO has developed a digester system that re-uses the digestate after the digester to dilute the digester content. The digestate is pumped from the effluent pit at the end of the AD vessel to a modified DAF system (DVO- DAF) to separate solids from the liquid digestate. This system reduces the total solids content of the digestate so that this liquid fraction is suitable for dilution of the high solids content wastes. However, the problem with the continuous recycling of digester effluent liquids from a digester is the potential for continuous accumulation of ammonium/ammonia in the liquid. Poultry waste, for example, is very high in protein compounds. These compounds biodegrade first into amino acids, and then from amino acids into ammonium. At a level of ammonium/ammonia above 3,500 ppm, ammonium/ammonia can become toxic to the methanogenic bacteria in the digester. Without a means to remove the ammonia, a digester will become acidic and eventually fail.

The DVO digester therefore includes an N stripping system and the ammonia is scrubbed from the air by means of H_2SO_4 into an AS.

After a modified DAF, the solid fraction is dewatered with a screw press ("squeezer").

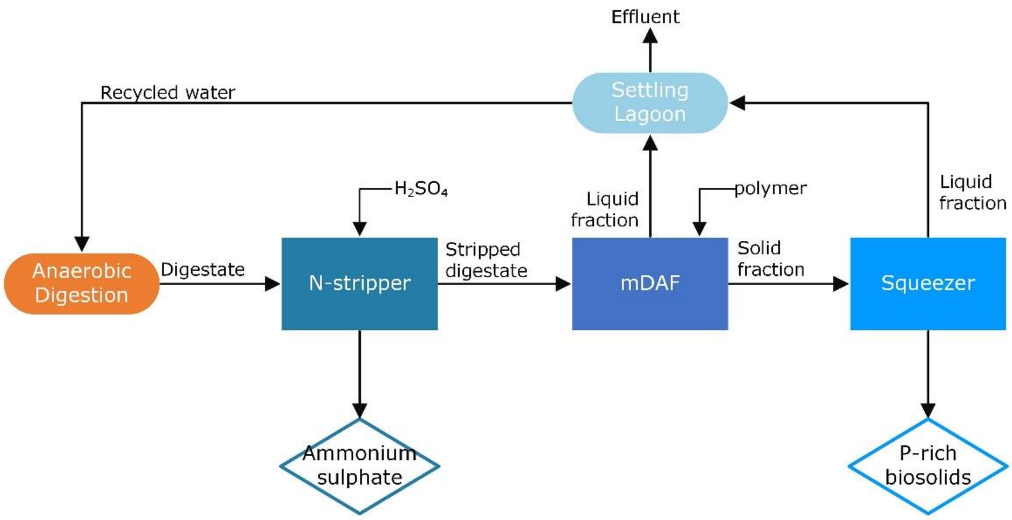

Figure 6-1 Final process scheme of the project designed by Rika biotech for the to build Fridays biogas plant.

Table 6-2 Composition of the end products for Rika biotech at the Fridays biogas plant (estimation), including nitrogen (N), phosphorus (P) and potassium (K).

After	N stripping-scrubbing	DVO-DAF	
Product	N stripped digestate	Liquid fraction	Solid fraction
Mass (kt/year)	150	112	42
Dry matter (%)	7	2.8	20
N total (g N/kg)	3.39	0.80	9.90
NH_4-N (g N/kg)	1.79	0.55	4.90
P total (g P/kg)	0.77	0.12	2.40
K total (g K/kg)	3.08	1.70	6.40

Labour

Labour requirements are estimated to be 2-3 full time employees/technicians plus back office support.

Energy

The waste heat from the CHP, in the form of hot water, is collected from both the engine jacket liquid cooling system and from the engine exhaust (air) system. Approximately 30 to 60% of this waste heat is utilized in the AD system. The remaining waste heat can be used by the farm as a replacement for hot water production (reducing the need for natural gas or propane purchases) and for in-floor heating of the farm and holding areas, as required.

Average electricity demand for the whole plant is estimated at 355 kW/hour provided for by the biogas fired CHP. The biomethane upgrader requires 180 kW/hour max usage and the digester, ammonia recovery using together about 225kw/hr.

Destination of the end products

The solid fraction, may be utilized by the farm for cattle bedding replacement. Use of the solid fraction as bedding material typically comprises about 40 to 60% of the generated solid fraction. The residual 40 to 60% of the solid fraction solids may be sold via local solid fertiliser contractor(s) at an estimated sales price of GBP 5/tonne to other farms for bedding purposes or sold to after-markets, such as nurseries and composters, for soil amendment material.

Ammonium Sulphate will also be sold to local market at an estimated sales price of GBP 30/tonne in the form of blends with N-P-K digestate to add value.

Due to the possibility of selling the N-P-K products in the region, sales prices are not limited by relevant handling and transport costs.

Potential off-takers have been identified from the local farming and contracting community for the digestate and ammonium sulphate and these discussions have informed the design of the nutrient recovery equipment.

SWOT analysis

Strengths

- Simple design of the digester and nutrient recovery.
- Cost effective price to build.

Weaknesses

- US technology solution that must be implemented for the first time in Europe

Opportunities

- Sale of liquid fraction and ammonium sulphate.
- • Emerging issues around manure in Europe open an opportunity for the plug flow AD reactor design employed by Rika.

Threats

- Competitive technologies are emerging in Europe that may be better suited to take quick advantage of the EU market from a regulatory and market familiarity viewpoint.
- Development of a niche market: the “magic dirt” product for retailers/consumers.

In 2018, the project has a planning permission, a grid connection and funding. After a delay of more than a year, the UK Government finally introduced new renewable heat tariffs in May 2018 for which RIKA applied. Initially it was expected that the AD plant and digestate processing at this farm would be operational by the end of 2019. Though construction started in 2019, it became evident that the plant would not be running in 2019 due to serious delays in the construction of the digester.

In 2020 RIKA Biotech, sold/handed over the project at Fridays (Kent, UK) and Wijster (NL) to GreenCreate, who builds, owns & operates integrated biological waste-to-value systems.

There are currently only 3 DVO digester systems operational in Europe, more precisely in Serbia and Denmark (https://www.dvoinc.com/gallery.php).

II.1.4 Impact of SYSTEMIC

For Rika Biotech, SYSTEMIC has been an interesting exercise for the team as it has introduced them to a wide variety of different technologies that would not otherwise have learnt about. There are myriad ways in which value can be derived from digestate and they have learnt that the correct solution for any given plant will very often be unique depending on location, feedstock and complimentary technologies. Rika has certainly been able to make use of many of the introductions they have received via SYSTEMIC when evaluating a designing other projects. According to them, SYSTEMIC has enormously increased their understanding of nutrient recovery options in the biogas sector as well as allowing us to understand the very important regulations that limit or govern what they can do with digestate and how best to try and add value.

II.2 Greengas AD (Ireland)

This chapter includes information on Greengas AD in Ireland from the fact sheet made in 2018 in the framework of SYSTEMIC.

II.2.1 Description of the company

GreenGas AD Plant is a farm based anaerobic digestion plant located near Shanagolden in County Limerick, Ireland. The plant was constructed in the course of 2010 and when commissioned in 2011 it was one of the first such plants in Ireland. Currently it operates 3.248 m³ of mesophilic digesters.

II.2.2 Business environment

Nutrient demand

Ireland's agricultural land is mainly grassland, and some cereal cultivation (Table 6-3).

Table 6-3 Crops percentage of UAA (utilised agricultural area: cropland + grassland) in the region of Greengas AD (Eurostat: Land cover overview by NUTS 2 regions, type of landcover % of UAA, 2015)

	Southern and Eastern Ireland
Grassland	87.7
Cereals	6.8
Maize	0.3
Potatoes	0.2
Sugar beet	0.1

For grassland, having high nitrogen (N), potassium (K) and sulphur (S) needs, ammonium sulphate is the ideal fertiliser. The region of Greengas AD is located in an area with possible sulphur deficiency (Figure 6-2). On S deficient soils, it is advised to apply 20 kg S/ha per year for grazed swards and for silage swards on S deficient soils, apply 20 kg S/ha per cut (Teagasc, Jonstown Castle, and Environment Research Centre 2016).

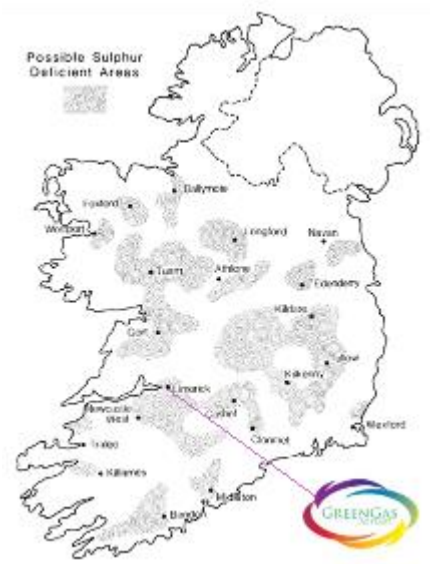

Figure 6-2 Areas in Ireland that are possibly deficient in sulphur (Teagasc et al. 2016)

Drivers for nutrient recovery

All of the digestate produced by Greengas AD is used on farmland controlled by the plant. Currently, this is enough but when the plant would wish to expand, more outlets will be needed for the digestate.

The high moisture content of digestate adds unnecessary transport and land application cost. By reducing the digestate volume and maintaining the nutrient levels the fertiliser value of the digestate is enhanced and significantly lowers transportation and application costs providing an important route to market for digestate.

II.2.3 Business case evolution during SYSTEMIC

Feedstocks

The feedstock of Greengas AD is mainly consisting out of food waste and dairy manure (Table 6-4).

Table 6-4 Origin of feedstock at the Greengas AD biogas plant, expressed in kton of substrate

Type	Mass (kton /year)
Poultry manure	1
Dairy manure	7
Food waste	10
Dairy sludge	3
Total	21

Biogas production

Table 6-5 Composition of the biogas at the Greengas AD biogas plant.

Component	Estimation
CH_4 (%)	57.8
CO_2(%)	38.2
H_2S (ppm)	170
O_2 (%)	0.8
N_2 (%)	3.2
Siloxanes (‰)	0.1
Total biogas production (Mm^3)	2,424
Biogas per tonne of feedstock (m^3/t)	~65

Digestate treatment cascade

All digested feedstock is sanitised by heating to 72°C for over one hour in 25 m^3 batches.

Table 6-6 Estimated composition of digestate at the Greengas AD biogas plant.

	Digestate (% of total solids)
N total (g N/kg)	8.8
NH_4-N (g N/kg)	6
P_2O_5 (g P/kg)	3.6
K_2O (g K/kg)	5.9

Energy-CHP

The plant was initially built with a CHP capacity of 250 kW electricity but has undergone a number of up-grades and now operates since 2016 at 1MW electricity.

Labour

The plant operates with 2 full time employees and uses 4 local staff members on part time basis.

Destination of the end products

All of the digestate produced by Greengas AD is used on farmland controlled by the plant. The use of digestate has reduced the dependency on artificial fertiliser with little to no artificial fertiliser added.

II.2.4 Suggestion done in SYSTEMIC and BDP

Due to an increase in capacity in the plant and the resulting increase in digestate more digestate application options are needed. From their own experience, Greengas AD knows that farmers prefer low volumes with a high concentration of nutrients.

(Bio)thermal drying, using residual heat from the digester, could be interesting in their case. Mixing with ammonium sulphate could help create a N:P:K:S ratio more in line with the crop needs.

All information about these technologies can be found on the BDP.

A challenge might be that Irish farmers are reluctant towards unfamiliar products (e.g. compost) and this will probably be the same for digestate, scrubber salts, mineral concentrates etc. Yet, with demonstration of application, results on crop yield and quality and a reasonable price setting they will probably embrace it as fertiliser.

II.3 Biogas plant Makassar – Som energia (Spain)

This chapter includes information on the biogas plant in Makassar, Torregrossa, Spain from the fact sheet made in 2018 in the framework of SYSTEMIC.

II.3.1 Description of the company

Som Energia, a non-profit green energy consumption cooperative owns the biogas plant Makassar, which is operational since end 2013. The plant has 17,000 m³ mesophilic digestion capacity. Daily monitoring of the operation of the plant is carried out by Som Energia by means of a remote monitoring system and follow-up meetings with the plant operators.

II.3.2 Business environment

The biogas plant is located in the municipality of Torregrossa (Catalonia) in 2012 and started in 2014. The digesters operate thermophilically and the plant is located in an area with intensive pig breeding and slurry treatment plants. It is also in a vulnerable area for nitrate pollution.

Drivers for nutrient recovery

At the moment digestate has no (negative or positive) value in Spain and the land to spread the digestate on in the area is limited. The changes in the new tariff framework (Royal Decree 413/2014) force Som Energia to find the balance between the operating costs, the electrical production and the number of hours of operation but always with the objective of producing the maximum amount of green energy possible.

II.3.3 Business case evolution during SYSTEMIC

Feedstocks

The plant is located close to a pig farm which supplies pig slurry (60% of the digester’s input) (Table 6-7. Organic biological waste contributes for 40% of the yearly feedstock and the biogas plant receives a gate fee for processing this waste.

Table 6-7 Origin of feedstock at the Som energia biogas plant, expressed in kton of substrate (2018)

Type	Mass (kton /year)
Vegetal fat	1.2
Municipal waste water sludge	4.5
Water with oil form the food industry	2.4
Organic household waste	2.4
Water from vegetable extracts	1.5
Pig slurry	17.8
Total	29.8

Biogas production

Table 6-8 Composition of the biogas at the Som energia biogas plant.

Component	Estimation
CH_4 (%)	65-70
CO_2(%)	30-50
H_2S (ppm)	0-25
O_2 (%)	0.02
Total biogas production (Mm^3)	1,275
Biogas per tonne of feedstock (m^3/t)	42.78

Digestate treatment cascade

Pig slurry and organic waste are received in concrete ponds and metal tanks in the floor. They are pumped to the mixing tank and from there to the digesters.

These are working in series and are equipped with a gasometer of double cover to store the gas. After a retention time of approximately 40-60 days the digestate passes to the open lagoons (11,000 m^3).

Table 6-9 Estimated composition of digestate at the Som energia biogas plant (2017).

	Digestate
Mass (kton/year)	27
NH_4 (g/kg)	0.003
P_2O_5 (g/kg)	0.409
K_2O (g/kg)	1.096

Energy-CHP

The biogas is cleaned by an active carbon filter and valorised in a CHP (500kW). Green electricity is in-jected to the grid. The thermal energy is used to heat up the digesters and on the neighboring farm.

In 2017 Biogas Plant Makassar produced 2.701 MWh and is estimated to produce 3.200 MWh in 2018.

The feed-in tariffs were in 2014 150-160€/MWhn, however the ours of production were limited.

Destination of the end products

The digestate is collected from the lagoon for direct application to field. The 30,000 tonnes of digestate per year are used on 524 ha of land and no disposal costs are charged.

II.3.4 Suggestion done in SYSTEMIC and BDP

Since there are no subsidies for biogas in Spain, the biogas plant cannot make large investments in expensive nutrient recovery technologies.

SYSTEMIC suggest therefore to investigate if the first step of NRR is possible: separation of the digestate by means of a centrifuge or screw press, because it is a simple and relatively cheap way to introduce nutrient recovery.

Ammonia losses could be reduced by covering the digestate lagoon, installing air washers and learning more about low NH_3 emission application techniques.

II.4 Emeraude BioEnergie – Cooperl (France)

This chapter includes information on the biogas plant Emeraude BioEnergie in Lamballe, France from the fact sheet made in 2018 in the framework of SYSTEMIC.

II.4.1 Description of the company

Emeraude bio-energie is a collective project initiated by Dénitral, subsidiary of the Cooperl group. Created in the 1990s to solve the problems of lack of spreadable surfaces, Dénitral is now specialised in the implementation of organic slurry treatment plants on pig farms.

II.4.2 Business environment

Emeraude Bio-énergie is be located in the municipality of Lamballe, in the industrial site of Ville Es Lan City, 2 km from the agglomeration, right next to the Cooperl's main slaughterhouse. This project will complete the environmental centre, which already receives the organic materials collected from Cooperl pig breeders and waste streams from the meat processing industry. It will include 14,700 m³ mesophilic AD capacity.

Drivers for nutrient recovery

With Emeraude bio-énergie, Dénitral wants to consolidate its activity and go further in the protection of the environment by valuing the waste it collects. Tthey would like to compare the digestate treatment cost of evaporation and stripping an find out the benefits of commercilising ammonia sulfate solution or in cristallised form.

II.4.3 Business case evolution during SYSTEMIC

Feedstocks

25% of the input of the digester is the solid fraction of pig manure, which is supplied by a hundred farms (average size of 100 sows) mainly located in the department of Côtes d'Armor. A lot of these farms work with the TRAC system (V scrapping separating), which integrates manure separation in the building.

40% of the feedstock is slaughterhouse wastewater of the Cooperl slaughterhouse and 25 % recycled water from the liquid fraction of the digestate.

Table 6-10 Origin of feedstock at the Emeraude BioEnergie biogas plant, expressed in kton of substrate (2018)

Type	Mass (ktonne /year)
Slaughterhouse waste water (6-8% DM)	65

Solid pig manure (30% DM)	38
Recycled water for dilution	53
Total	156

Biogas production

About 530 m³ of bio-methane/hour is purified and directly fed into the gas grid where it will circulate with natural gas and can be directly distributed and used by consumers in Lamballe and its surroundings. This will represent 79 million kilowatt hours/year, i.e. the annual natural gas consumption of about 3,100 single-family homes.

The biogas is not valorised by means of a CHP to produce electricity because the current process, where bio-methane is injected directly is more suitable for large installations and guarantees a better energy efficiency.

Table 6-11 Composition of the biogas at the Emeraude BioEnergie biogas plant

Component	Estimation
CH_4 (%)	66
CO_2(%)	32.2
H_2S (ppm)	61
O_2 (%)	0.11
Total biogas production (Mm^3)	4.8
Biogas per tonne of feedstock (m^3/t)	30.7

Digestate treatment cascade

The existing reception infrastructures on the industrial site will be modernised and the feedstocks, already stored on the site, will be transported by hermetic pipes to the digester.

The digestate is separated by a centrifuge in a liquid fraction and a solid fraction. Ammonia in the liquid fraction is removed by an ammonia stripper/scrubber and recovered as an ammonia sulphate solution.

The ammonia-free liquid fraction in further treated in a waste water treatment.

Table 6-12 Estimated composition of digestate at the Emeraude BioEnergie biogas plant (2018).

Input		Digestate		Solid fraction	Liquid fraction	N stripped LF
After		Centrifuge		Crying	N stripping-scrubbing	Nitri-denitrification
Product	**Digestate**	**Solid fraction**	**Liquid fraction**	**Dried solid fraction**	**Ammonium sulphate**	**Dischargeable water**
Mass (ktonne/year)	156	35.8	170	13.3	7.2	91
Dry matter (%)	7.5	23	1.8	85		
N total (g N/kg)	6	9.7	3.2	21	7.7	
P2O5 (g /kg)	4.1	13.7	0.7	46		
K2O (g /kg)	2.3	1.37	1.7	26		

Destination of the end products

The dischargeable water is reused for the operation of the cooperative's industrial sites (non-food processes).

The solid fraction is transported to Fertival (on the other side of the railroad) where it is dried and sold as natural fertilisers.

II.5 Biogastur (Spain)

This chapter includes information on the biogas plant in Navia, Spain from the fact sheet made in 2018 in the framework of SYSTEMIC.

II.5.1 Description of the company

BIOGASTUR originated in 2009 with the objective of promoting resource management projects (waste) of the primary sectors, based on biogas generation as well as the production of biological fertilisers from the final digestate. In 2017 the construction started of one of the biggest projects in renewable energy. Biogastur wants to integrate wastes as a resource, through optimal treatment and guaranteeing its traceability.

The biogas market in Spain needs still to be developed and more specifically agro-industrial biogas, where Biogastur will be leading in production capacity, the technologies implemented and the level of management of waste and GHG reduction. They consider it essential to be at the forefront of technology and information which is developed within the European framework, covered by the Horizon 2020 program objective.

II.5.2 Business environment

Drivers for nutrient recovery

At the moment, struvite is not needed as a fertiliser in the region, but there is a need for custom-made ferilisers. Blending of different recovered nutriets (N-P-K) could create a market.
Nitrogen is not recovered in the biogas plant but is converted to the environmentally harmless form N_2.
Ammonia stripping-scrubbing would create a problem for use of the ammonium sulphate as a fertiliser, since this product is subject to REACH regulation in Spain.

II.5.3 Business case evolution during SYSTEMIC

Feedstocks

The biogas plant would treat cattle slurry (87.5% of total yearly input), crop residues and dairy waste from an agreement with a milk cooperative. Each count for 6.25% of the total input.

Table 6-13 Origin of feedstock at the Biogastur biogas plant, expressed in kton of substrate (2018)

Type	Mass (ktonne/year)
Cattle slurry	350
Agro-industrial residues	25
Dairy waste	25
Total	400

Biogas production

This plant will be producing 17 Mm^3 of biogas per year.

Digestate treatment cascade

Feedstocks are digested in a residence time of 3-4 weeks. The digestate is separated by a centrifuge in a liquid fraction and a solid fraction.

The liquid fraction is treated by MBR-NAS® process. This is a membrane reactor where a classic biological activated sludge system removes the nitrogen and organic material by oxidation and nitrification-denitrification to N_2 gas.

By applying the ANPHOS® system to the liquid fraction, phosphorus is recovered as 1 tonne of struvite per day.

The solid fraction is dried to a dry matter content of 77-90%. Only if a water content of less than 20% is preferred, part of the biogas would be used in order to dry the solid fraction.

Table 6-14 Estimated composition of digestate at the Biogastur biogas plant (2018).

Input		Digestate		Liquid Fraction	Solid fraction
After		Centrifuge		ANPHOS®	Drying
Product	**Digestate**	**Solid fraction**	**Liquid fraction**	**Struvite**	**Dried solid fraction**
Mass (kton/year)	360	25	300	3	24
Dry matter (%)	10	70	12		90
N total (g N/kg)					2.7
P (g P/kg)					1.5
K2O (g /kg)					2

Energy-CHP

The biogas will be valorised into 30 GWh of energy per year by means of 3 CHP engines (Jenbacher 420) of each 1500kW electricity with an efficiency of 42%. The heat coming from the CHP, hot water, hot air and flu gasses will be recovered as 4692 kW thermic energy.

The CHP can only work efficient if the concentration of hydrogen sulphide is below 200 ppm. To remove hydrogen sulphide from the biogas, the BIDOX® system is used, which is a patented system based on biological desulfurization. Here, anaerobic bacteria carry out the oxidation of sulphate and the sulphate is removed in the form of a very dilute sulfuric acid solution. The concentrations of H_2S left in the biogas are lower than 1 g/L.

Destination of the end products

Biogastur will use the produced biogas fit the own truck fleet with which they can collect manure and distribute their fertilisers to farmland.

Systemic large-scale eco-innovation to advance circular economy and mineral recovery from organic waste in Europe

Consortium

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The SYSTEMIC project has received funding from the European Union's Horizon 2020 Framework Programme for Research and Innovation under Grant Agreement no. 730400

Horizon 2020