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A roadmap for the transition towards a circular economy for nutrients recycled from organic waste streams at anaerobic digestion plants

Experiences from the EU H2020 project SYSTEMIC

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PREFACE

This booklet describes the roadmap for the introduction of biobased fertilisers that are produced from anaerobic digested organic waste streams in order to utilise all available nutrient sources for European food production. The SYSTEMIC project was funded by the EU H2020 programme (project number 730400) and focuses on the demonstration of nutrient recovery and reuse technologies implemented at five large scale anaerobic digestion (biogas) plants which was partly funded by the project:

- Acqua & Sole (Italy)
- Am-Power (Belgium)
- BENAS (Germany)
- Groot Zevert Vergisting (The Netherlands)
- Waterleau NewEnergy (Belgium)

The nutrient recovery techniques were further evaluated in terms of agronomic, environmental, economic and legislative aspects. More than thirty other biogas plant operators, who were interested in these new developments, contributed actively regarding the options for a broader implementation.

This roadmap is based on lessons learned from the SYSTEMIC project (www.systemicproject.eu) and the official publications which are indicated at the end of the booklet.

We do hope that this roadmap provides comprehensive practical information for decision making by policy makers, biogas plant operators, and farmers regarding required further steps towards a more circular economy, agriculture and food system.

Oscar Schoumans
Coordinator of SYSTEMIC

Content

1. Transition of the European agricultural market

Guaranteed food supply by increasing food production and improving the agricultural food production system has always been an important European strategy. However, over the last two decades the protection of the water, air and soil quality has become more important. Consequently, many of the European Directives, like Nitrates Directive (1991), Water Framework Directive (2000), Ambient Air Quality Directive (2008) have had great impact on farmers managements plans and their investments in order to reduce nutrient losses.

More recently, there is an increasing awareness that the raw materials required for agricultural production are limited and that our organic waste streams must be optimally reused and utilised to increase the nutrient use efficiency of agricultural systems (Circular economy strategy, 2015). In addition, Europe needs to become climate neutral in 2050 and, as a consequence, the European Commission (EC) has decided that nutrient losses have to decrease with at least 50% and that the use of mineral fertilisers will be reduced by 20% in 2030 (Green deal, 2020 and Farm to Fork strategy, 2020). Consequently, a further transition is needed towards a European market of sustainable, climate-neutral and resource-efficient products.

Available organic waste streams, like excess manure, sewage sludge and food waste, are complex materials that require high tech and rather expensive technologies to extract valuable components like nutrients, water and/or organic matter, for reuse within agricultural production systems. Within the SYSTEMIC project, these different types of organic waste streams were processed using different nutrient recovery and reuse (NRR) technologies implemented at large scale centralised anaerobic digestion (AD) biogas plants.

The main goal was achieved by producing new biobased fertilisers out of complex organic waste as a substitute for (synthetic) mineral fertilisers and digestates, and to produce soil conditioners which can maintain soil fertility and increase carbon storage in the soil.

Although the physical production of biobased products from organic waste streams is technically feasible, additional incentives are needed for a broad market introduction. Generally speaking, biobased products are not yet cheaper compared to synthetic fertilisers due to the high-tech technologies required to recover valuable nutrients out of complex organic waste streams, an unequal economic playing field and legal barriers hindering marketing, and a degree of end-user reluctance towards these unfamiliar new products.

In the current market-driven economy, the price of producing biobased fertilisers compared to that of producing synthetic fertilisers is highly determinate of broad acceptance even if the CO_2 footprint and greenhouse gas emissions are lower. A more environmental and climate-oriented market approach is needed to achieve a circular economy that meets the objectives of the Green Deal. It was shown that a specific technology cascade can prove to be cost-effective for a biogas site, depending on the local boundary conditions in which the plant is operating and the fact that the volume of all produced products is smaller compared to original digestate volumes, resulting in lower transport costs than those of unprocessed digestate.

This roadmap shows the current status of large-scale valorisation of organic waste streams into valuable biobased products including options for embedding in agricultural practice as fertilising products. Major steps were taken, but broad implementation is needed and therefore, important recommendations are given.

SYSTEMIC has demonstrated that large-scale industrial biogas plants can produce biobased / mineral fertilisers from complex organic waste streams by using innovative Nutrient Recovery and Reuse technologies. However, many plants are working at or near break-even point economically. Other instruments and incentives are required for broad implementation within a Circular Economy in order to meet with the objectives of the EU Green Deal.

2. Role of large-scale biogas plants as organic waste processing pioneers

Agriculture, particularly livestock farming, is responsible for about 10% of current European greenhouse gas emissions (Eurostat, 2018), of which 55% is due to handling, storage and use of livestock manure, while the remainder is due to emissions from soils. Biogas converted to biomethane will contribute up to 100 million tonnes of Oil Equivalent (Mtoe) (of 700-900 Mtoe total energy consumption) in the 2050 zero-emission energy mix as outlined in the SYSTEMIC business case analysis. Zero-emission scenarios require carbon positive agriculture, i.e. sequestration of carbon in soils.

Anaerobic digestion reduces manure and waste-borne emissions. Digestate derived products can replace mineral N-P-K fertilisers and thus save greenhouse gas emissions from mineral fertiliser production, which equals some 3-4 kg CO_2 per kg N produced in Europe. Compressed or liquified biomethane replaces fossil fuels for heavy goods vehicles and shipping, saving additional greenhouse gas emissions.

For these purposes, large fractions of digestible organic waste must be converted to biogas. These wastes may include manure, agricultural residues including non-edible parts and cover crops, food and beverage industry waste, expired foodstuff and sewage sludge. It is simply impossible to use electricity as sole carrier for industry and transport in the net-zero 2050 scenarios, for material resource needs related to electricity storage. There is a global need to use all available resources that can be harvested by traditional and constant supply technologies because we cannot manufacture the batteries needed for intermediate storage from available mineral resources withing the given timeframe (Michaux, 2021).

Photo of one of the demonstration plants: Groot Zevert Vergisting (Beltrum, The Netherlands)

In regions with high livestock density (the Netherlands, Flanders), overproduction of manure requires digestate to be processed to tailor-made fertilising products for direct use by consumers or to secondary raw materials for the fertiliser industry. Products need to be made in such way that nutrient content tailors to the nutrient requirements of crops in the targeted agricultural markets. Manure-derived inorganic products may be processed to so-called **RE**covered **N**itrogen from man**URE** (RENURE) fertilisers replacing synthetic nitrogen (N) fertilisers in the future. This is in compliance with efficiency criteria allowing their use in excess of the 170 kg manure derived nitrogen ha^{-1} $year^{-1}$ (limit in nitrate vulnerable zones under determined conditions; Huygens *et al.*, 2020).

The technology processes demonstrated in the SYSTEMIC project are complex and require a minimum capacity of several tens of thousands tonnes of substrate to have an economical scale advantage, which cannot be provided by individual small farms. Additionally, cost effective energy conversion from feedstock to biogas production needs a substrate mix with high calorific value. These requirements can only be met by biogas plants collecting substrates from several suppliers, including, for example, the food processing industry.

Biogas plants consequently have at least two synergetic functions in a circular economy:

1. Converting organic waste and residues to renewable, carbon neutral energy carriers
2. Transforming unstable substrates to nutrient and carbon efficient fertilising products

SYSTEMIC stated that a frequently changing regulatory framework and the highly volatile, if any, compensation for saving greenhouse gas emissions have failed to provide sufficient support for robust growth of biogas plants across Europe. The ambitious emission reduction targets of the "Fit for 55 Package" should include a Europe-wide legal framework by which CO_2 emissions are considered as pollution, entailing a cost and that techniques contributing to greenhouse gas savings are rewarded. While nitrogen fertiliser production is already included in the European Emission Trading System (ETS), a similar mechanism must be set-up for agricultural ("Carbon Farming") and organic waste conversion activities like anaerobic digesters including nutrient recovery.

3. Introduction of innovative nutrient recovery and reuse technologies

For five European large scale biogas plants ("Demonstration Plants"), SYSTEMIC demonstrated the performance of implemented innovative technologies to recover valuable fertilising products and soil improvers from digested waste (biobased fertilisers; BBFs). In some cases, clean water was also produced as a potential commodity, water was removed to reduce transport costs of produced digestate and fertiliser products. The technologies implemented at the demonstration biogas plants are mechanical separation, ammonia stripping-scrubbing, evaporation, phosphorus (P) solubilisation and precipitation, membrane filtration including reverse osmosis, ion exchange, and drying.

Although the biogas plants owners often started with technical innovations to produce new types of products against lower costs, they became aware that they should pay more attention to the importance of their specific business environment and associated business case. This business environment is site-specific and should include at least regional market analyses for the produced biobased fertilisers, including the legal framework, premiums and incentives, and acceptance of the products. The business case should not only take into account all cost-benefits related to the whole nutrient recovery valorisation chain (i.e. CAPEX and OPEX), but also the availability of water, energy and heat from a combined heat & power installation (CHP), technical know-how of the staff and service chain support, transport costs, and (adapted) application method of the biobased products on fields. A safe and financially beneficial use of all produced end- and by-products should also be regarded.

While revenues from energy conversion and gate fees to process organic waste are the main contributors to the business case, revenues from the produced soil improver and mineral and organic fertilisers are increasingly considered by the plant-owners to contribute to a positive business case. However, both have to be in line with prices on the market, which can vary remarkably over time. The consequences for pioneers of large-scale biogas

Photo of the Evaporator-condensator installation at AmPower (Pittem, Belgium).

plants, who invested in the valorisation of organic waste streams by means of nutrient recovery, are huge when prices are going down, like in 2021 in the Netherlands for manure processing.

Another important experience was that large scale implementation of rather new nutrient recovery technologies on organic waste streams is complex and very sensitive regarding composition of the feedstock, functional design of each unit of equipment, and operational conditions. The construction period is often 1-2 years before commissioning, and starting-up is a labour-intensive phase of testing and fine-tuning, which can last up to a year or even longer. This long period has to be financially bridged until the revenues from a stable running system start coming in. All demonstration plants are now happy with their configuration of the nutrient recovery installation and product quality, although improvements, as always, can and should be made to create a business case that is resilient and flexible towards changes in market and (environmental) legislation.

All technologies mentioned above **can be regarded as cost-effective under certain business conditions**, depending on the local boundary conditions, availability of low-cost heat and the market environment (storage, transport costs, potential revenues) in which the plant is operating. For a different biogas plant, in a different region, the technology might not be cost-effective at all.

SYSTEMIC showed that the involved nutrient recovery and reuse technologies are high-tech and frequently require input of chemicals which do not make them a cheap and easy solution for most biogas plants. However, larger biogas plants have an economical advantage because of their scale, more technically experienced staff, and the entrepreneurial spirit of owners and operators who have a feeling for the requirements of their regional markets. The design of the technology cascade is frequently tailor-made for a specific biogas plant, to optimise the business case within its specific business environment. The investment options always need to be weighed in their full business context, now and in the (near) future. For example, a flexible, modular system of a cascade of nutrient recovery and reuse technologies, can respond to changing market conditions.

4. Product quality and quantity of biobased fertilisers

Implementation of nutrient recovery and reuse technologies changes the initial composition of the untreated digestate and results in different recovered end-products that might have potential to be used as biobased fertilisers. The NRR technologies mostly concentrate nutrients in the recovered end-products and often reduce the water content, which leads to lower volumes for transport and hence lower transport costs economically and environmentally.

The main recovered end-products from digestate, within the SYSTEMIC project, are ammonium sulfate solution, concentrate from reverse osmosis, evaporator concentrate, condensed ammonia water, precipitated phosphate salts, low phosphorus (P) soil improver, low nitrogen (N) organic fibres, and digestate, (dried) solid fraction of treated digestate, calcium carbonate sludge, and purified water.

The assessed product composition indicates that there is variability within the same group of end-products (e.g., ammonium sulfate solution) that are produced at different NRR facilities. As expected, this is influenced by the process conditions, type of treated feedstock (e.g., sewage sludge, animal manure, food waste, …), addition of chemicals and additives (e.g., polymers), type of processing units (e.g., screw press or centrifuge for mechanical separation), etc. Nevertheless, product stability in nutrient composition can be achieved at an individual NRR facilities by good operational management, including a regular and dedicated monitoring campaign. Even though NRR technologies result in higher concentration of nutrients in biobased fertilisers (as compared to the untreated digestate), the nutrient content typically is still lower than in conventional synthetic mineral fertilisers.

Moreover, the recovered end-products will mostly be present in liquid form (except solid fractions and evaporator concentrate sludge) as compared to the granular form of synthetic fertilisers. Consequently, application of the recovered end-products as biobased fertilisers often requires a different type of agricultural machinery and higher (more regional) transport volumes compared to the application of conventional synthetic mineral fertilisers.

Evaporator concentrate
Am-Power

Evaporator concentrate
Waterleau

Ammonia water

Waterleau

Ammonium sulfate and calcium carbonate
BENAS

Mineral concentrate

Groot Zevert Vergisting

dried solid fraction

Am-Power

dried solid fraction

Waterleau

wet fibers

BENAS

P-low soil improver **sludge and dried calcium phosphate**
Groot Zevert Vergisting

Next to the nutrient composition, it is also important to pay attention to the content of pathogens, (heavy) metals and organic micro-pollutants. In recovered end-products examined in the SYSTEMIC project, pathogens were absent. In general, this is quite simple to achieve this by sanitation of a product (e.g. 1h at 70°C). Heavy metals were within expected range that is not detrimental for plants and soil quality. However, accumulation of iron (Fe) and aluminium (Al) was notable in a solid fraction of digestate at a NRR facility that uses the Fe and Al based polymers to increase phosphorus separation efficiency from digestate into the solid fraction of digestate. Accumulation of metals is also dependent on the feedstock treated in the anaerobic digesters (e.g., high Fe content due to the processing of food industry sludge). In regard to organic micro-pollutants, the number of compounds (herbicides, pesticides and pharmaceuticals) detected varied between the plants and can be related to the feedstock of the plant. In most cases, organic micro-pollutants end up in the organic-rich solid fraction of digestate. Remarkably, no residues of pharmaceuticals were detected in digestate from sewage sludge after thermophilic digestion. Ammonium sulfate solution was free of residues from herbicides, pesticides and pharmaceuticals. Finally, if the acidity pH value of the recovered products is above 7, volatilisation of ammonia during the storage and application of the products can occur. Therefore, distribution of the products by direct injection (of liquid products) or immediately incorporating (of solid products) into the soil is advised.

SYSTEMIC showed that nutrient recovery and reuse technologies result in recovered end-products that contain higher ratio of plant available forms compared to initial feedstock (i.e., digestate), and as such have potential to be used as substitutes for synthetic fertiliser or untreated manure/digestate. However, the nutrient stability and lower nutrient concentration, as compared to synthetic mineral fertilisers, remain one of the biggest challenges for their market uptake, next to pricing of the products and the legal aspects.

5. Agronomic performance

Biobased fertilisers produced from nutrient recovery and reuse (NRR) technologies have nutrient compositions that in general do not meet crop nutrient requirements. Therefore, a BBF can be considered as a secondary raw material to produce tailor-made fertilisers (TMFs). A TMF is a blend of multiple BBFs or a blend of BBF(s) and synthetic mineral fertiliser(s) that meets which the fertility status of the soil and the nutrient requirements of the crop. For this to occur, it is important not only to identify the right components of the TMFs, but also in which ratio the BBFs should be blended. Finally, the created TMF needs to be applied in a way that avoids potential emissions, and under best management practices. i.e. in accordance with '4R nutrient stewardship': right source, right rate, right time and right place.

Within the SYSTEMIC project, the following two products have potential to be used as a component of TMF: (1) ammonium sulfate solution and (2) mineral concentrate from reverse osmosis. While mineral concentrate contains at least 90% of nitrogen in mineral form, ammonium sulfate is 100% mineral nitrogen. Storage tanks for these products are designed in accordance with regulations, in a way that uncontrolled leakage of liquid can be eliminated. Both products are advised to be applied on fields by means of injection in order to prevent ammonia emissions. For blending, attention needs to be given to possible chemical reactions which might lead to the formation of hydrogen sulfide (H_2S) gas which is toxic and lethal.

In general, results from SYSTEMIC project field trials show that the use of BBFs can result in a similar crop yield as with the use of conventional mineral N fertilisers, provided that the principles of 4R are followed. Furthermore, in SYSTEMIC field trials there were no significant differences observed in regard to the nitrate residue in the soil layer of 0-90 cm. However, in some instances lower crop nitrogen uptake was observed, which led to lower

MINERAL CONCENTRATE
GROOT ZEVERT VERGISTING

LOW-P SOIL IMPROVER
GROOT ZEVERT VERGISTING

AMMONIUM SULFATE FIELD SPRAYER
BENAS

Field trial in Croatia

nitrogen fertiliser replacement values (NFRV) for certain biobased products. In a Belgian 1-year trial, liquid fraction (LF) of digestate had a NFRV (175±99 %) similar to the a conventionally used synthetic fertiliser, calcium ammonium nitrate (CAN; 126±27%). Low precipitation at the beginning of growing season and heterogeneous growth of maize plants starting from a heterogeneous germination might have led to the high standard deviations of the calculated NFRVs. In a Croatian 2-year field trial, the liquid fraction of digestate in combination with NPK resulted in highest NFRV of 83±9 % as compared to the sole use of conventional NPK fertiliser. In an Italian 3-year field trial, maize plants were able to use the nitrogen provided with the digestate (and ammonium sulfate solution as a top dressing) with similar efficiency to that of maize plants provided with urea (NFRV of digestate is 83.7%). In general, studies on NFRVs tend to show a notable variation across different field experiments. This variation stems from the effects of variable weather and soil conditions on the performance of both biobased products and the used references.

Within the SYSTEMIC project, finding the right balance between nutrients and improvement of nutrient use efficiency (NUE) while minimising their effects on the environment, has been identified as a major challenge. In finding this balance, challenges ahead are in the production of the right sources with the right trustworthy quality (nutrient balance, reliable NUE) and the right application method for enhancing NUE while minimising losses to the environment (ammonia, greenhouse gasses, nitrate leaching) and losses from storage of tailor-made fertilisers.

6. Sustainability aspects

Introducing biobased fertilisers as substitutes for synthetic mineral fertilisers and digestate or manure will always lead to a change in amounts of applied nutrients (macro-meso-micro nutrients including heavy metals) due to differences in the composition of the products. Consequently, there will be a change in losses to the air, accumulation or depletion in the soil and losses from the rootzone to deeper groundwater.

By performing an Environmental Impact Assessment, the impact on the environment of changes in nutrient management strategy for representative soil-crop combinations within SYSTEMIC was predicted by means of peer reviewed models. The environmental impact is assessed for gaseous emissions of ammonia (NH_3), nitrous oxides (N_2O) to the air, nitrate (NO_3) leaching to groundwater and phosphorus (P) and heavy metals (chrome, arsenic, lead, cadmium, nickel, zinc and copper) accumulation and losses from the rootzone to groundwaters. In addition, the changes in carbon stock in the soil were quantified including the associated CO_2 emissions.

In general, it is concluded that produced biobased fertilisers can be used as substitutes for digestate and/or mineral fertilisers and often give quite similar environmental impact in terms of emissions to the air, nitrate and phosphate losses and heavy metal losses. Sometimes, there is a negative or positive environmental impact depending on the soil-crop combination and the composition of the biobased fertilisers, which differ remarkably.

In none of the situations all crop-requirements (N, P, K and S) can be exactly met with fertilisation regimes that take application limits into account, not even in reference scenarios. In some cases this cause over-fertilisation in terms of phosphate, sulfate and/or heavy metals. If, besides nitrogen application standards, also phosphorus equilibrium fertilisation is taken into account the additional losses are often prevented. If ammonium sulfate rich in sulfur is used as biobased fertiliser, it is recommended to take into account crop specific sulfur recommend-dations, in order to limit sulfate accumulation in soils and losses. Leaching to ground water has negative impacts on (drinking) water quality.

Besides an environmental impact assessment, also a Life Cycle Assessment (LCA) was performed with boundaries from cradle to upper farm gate, covering the production process and transport of products while excluding storage and use related impacts (which have been assessed by the Environmental Impact Assessment (EIA) and the evaluation of the Fertiliser Replacement Values (FRV) above.

All processes are of low impact because energy (heat and electricity) is typically from on-site conversion and organic waste derived. Apart from the demonstration plant BENAS, the feedstocks are impact-neutral waste. The use of process chemicals is limited to the absolute minimum to achieve the required quality and functions in end-products. From the LCA perspective, process related impacts replace transport related impacts because processes successfully reduce mass flows, and consequently transport impacts (number of transports, transport distances). As long as the energy expenditure is renewable, i.e., taken from heat and electricity produced on site, the efforts of nutrient recovery are usually justified. The environmental effects of the various processes are lower than the effects of the transports they are replacing (transport of unprocessed digestate). Impacts from process chemicals are usually small, and where larger amounts are used, such as sulfuric acid for the production of ammonium sulfate, the product can fully replace an equivalent mineral fertiliser in terms of FRV, emissions and purity. Consequently, the same amount of acid would be used for an equivalent conventional product.

The LCA faced challenges in regard to the data quality and the frequent impossibility to distinguish between separation in response to feedstock / process related requirements and separation for the sole purpose of nutrient recycling. Consequently, process related LCAs are frequently based on assumptions. More important are the different FRV of nutrients in digestate and of nutrients in recycled products, which are not considered in the LCA due to the uncertainties and ambiguity of interpretations. Since the absolute amount of nutrients is the same before and after treatment, only the FRV can make a difference for use efficiency but is not reflected in the LCA.

SYSTEMIC concluded that in a sustainable circular economy, and also a linear economy, the application of each of the required nutrients should not go beyond the crop demand of that specific nutrient because, in the long term, nutrient losses will increase if no additional measures are taken. Under these conditions there are no severe negative impacts expected of the biobased fertilisers as produced by the demonstration plants, compared to conventional production of synthetic fertiliser alternatives.

7. Business cases

Currently, SYSTEMIC business cases depend on the availability of a national support scheme, which typically change frequently or are even totally absent in some EU Member States. Support schemes may consist of fixed feed-in tariffs for electricity or biomethane, or market premiums on top of the market price, or green certificates, all related to energy supplies. Nutrient recovery and reuse has never been subject to a support scheme. Producing biobased, tailor-made fertilisers can contribute to the viability of the business case, but cannot sustain the capital expenses and operations of a biogas plant. It can hardly sustain the nutrient recovery and reuse operations including capital expenses for their installation.

The added (nutrient use efficiency) value of tailor-made fertilisers is not yet reflected in product prices. Users would rather consider the origin than the nutrient value of the products. Considering the real value of converting organic waste into renewable energy and tailor-made fertilisers one must include:

- Bio-methane (bio-LNG/bio-CNC) is carbon-neutral or even carbon-positive - a fact that needs to be monetised (e.g. by carbon credits)
- Digestate-based fertilisers avoid CO_2 emissions from the use of untreated food and agricultural residues and from (open air) composting or incineration
- Nutrient (nitrogen) use efficiencies are up to 3 times higher in digestate-derived, tailor-made products than in unprocessed feedstock
- Use efficiencies are frequently comparable to conventional mineral N-P-K fertilisers.

Low hanging fruits are N-P-K blends which better correspond to the nutrient demand of crops. New business models such as have been developed by Groot Zevert Vergisting (potting soils) and BENAS (mulching mats and packaging material from the fibrous fraction) have the potential to significantly improve the revenues from customised products.

SYSTEMIC states that in the course of implementing the Fit for 55 Package, all anaerobic digestion-derived added values in terms of carbon-neutral or carbon-positive energy and fertilisers should be monetised. SYSTEMIC suggests to extend the European Emission Trading System (ETS) to agricultural and biogas activities and to allow stakeholders to benefit from saved CO_2 emissions from renewable energy and from carbon-neutral fertilising products.

8. Capacity building

Nutrient recovery and reuse requires investing in complex, high-tech technologies that need to be carefully operated, monitored and fine-tuned. They can help to produce end-products that are more concentrated than the initial digestate and can even be blended into tailor-made fertilisers that can be competitive with synthetic mineral fertilisers.

Optimising the nutrient recovery and reuse process and marketing strategy for tailor-made fertilisers requires extra investment, time and specialised skills, which most anaerobic digestion plant operators do not have. Since it is impossible to specialize in everything, large biogas plants already tend to outsource certain aspects or services from their business to external professionals, service companies or clearing houses. Hereby a part of the control is transferred and, to a certain degree, the prices for these services cannot be influenced by the biogas plant. This is why biogas plants often still tend to look inwards and try to manage every aspect themselves, which can be disadvantageous in the long term.

Circular economy needs cooperation and partnerships to thrive. For this, trust is needed. An example of a successful cooperation structure that can help relieve the burden of managing a biogas plant with NRR and profitable product marketing is being part of a big cooperative or company. This can also be a joint venture of several AD plants. This way, there can be transparency on the pricing and marketing, equal share in the cooperative instead of competition, and unhindered exchange of knowledge, experience and skills within the cooperative, and the risks and costs can be spread over a larger number of partners.

In SYSTEMIC it was seen that, when it comes to technologies, biogas plants tend to look for experiences from their peers and are open in sharing detailed information with each other, as long the plants are not in direct competition with each other.

SYSTEMIC has tried to facilitate this by the *creation of a network of European biogas plants* (Demo Plants, Associated Plants and Outreach Locations) and creating Living Lab meetings with other stakeholders including technology providers, research and policy makers.

This stimulated exchange of knowledge and experience even across national borders and helped to identify the bottlenecks regarding digestate treatment with nutrient recovery and reuse. It created a unique environment where the biogas plant owners were able to explore NRR in practice on a technical, business- and product-level.

The development of the *Business Development Package*[1] *including a nutrient recovery an reuse tool, farmer information sheets and plant videos* will ensure that the knowledge and experience exchange continues after the SYSTEMIC project and is expanded from the SYSTEMIC biogas plants to more biogas plants across Europe.

SYSTEMIC has shown that cooperation and partnerships with different stakeholders are key to ensure the further roll-out of nutrient recovery and reuse technologies, biobased (fertilising) products and the successfulness of new business cases of biogas plants with NRR in Europe. Therefore, SYSTEMIC developed an open and user-friendly access to practical information and experiences from peers, research and other stakeholders regarding NRR as an important pilar of circular economy.

[1] SYSTEMIC Business Development Package website https://systemicproject.eu/bdp

9. Legal aspects

The full potential of nutrient recovery and reuse from our organic wastes will not be recognised until the products can compete on a level playing field with other (conventional synthetic) fertilising products. Working with organic waste materials is complex and requires expensive technologies, and, like in many industries in our linear economy, at this moment reusing materials often comes at a higher cost than developing products from virgin materials. The technology to recover nutrients from organic waste is well developed and applicable at the industrial scale, as shown by the SYSTEMIC project. However, greater incentives are needed to stimulate the market for recycled nutrients in order to scale up the circular economy to enable the objectives of the Green Deal to be met.

The overarching legal framework governing agricultural activities in the EU is the Common Agricultural Policy (CAP) with the latest recast adopted in Qu3/2021 for enactment in 2023. The CAP is based on two Pillars: Pillar I comprises of direct payments and market measures, and Pillar II focuses on rural development policy. Both CAP Pillars allow for a variety of environmental measures, and from 2023 25% of Pillar I payments need to be assigned to so-called eco-schemes, which are to be proposed by Member States (MS) and mutually agreed between MS and the European Commission. Eco-schemes could and should cover compensation payments for eco-services of farmers that are not adding to the farmers' revenues, and could include, among others, payments for use of recycled nutrients.

Recycled products in compliance with the new Fertilising Product Regulation (EU) 2019/1009 (FPR) coming into force by 16th July 2022 will automatically achieve End-of-Waste status across Europe and thus will be freely tradeable across the EU, overcoming the barriers currently hindering the export of biobased fertilisers. In particular, organic and phosphorus rich solid fractions and ammonium sulfate will become tradable once covered by the newly introduced Component Material Category CMC15 in the EU FPR. It is important that at the short term the definition of designation of the Animal By Products as well as the criteria for their end points for fertilising products from manure will be set.

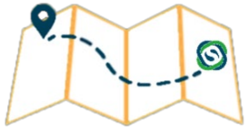
Furthermore, nutrient recovery processes like nitrogen stripping, evaporation, and nano filtration produces products that do not contain substances that may pose a threat to human health or the environment. Such products should be awarded ABP end point. Currently, Flemish SYSTEMIC partners located close to the French border do suffer from bureaucratic delays for getting permits to sell and use products in France.

The Nitrates Directive 91/676/EEC represents a barrier to use mineral recycled products, such as manure-derived ammonium sulfate, above 170 kg N/ha/y in nitrate vulnerable zones – most of the areas with high livestock density where SYSTEMIC partners in the Netherlands and Belgium are located. RENURE ("REcovered Nitrogen from manURE") criteria for highly nutrient use efficient manure-derived fertilisers have been proposed by the Joint Research Centre for exempting compliant products from the annual 170 kg N/ha limits. The following policy recommendations are given:

- The RENURE criteria needs to be approved and adopted in EU27 legally without delay.
- There needs to be harmonised implementation of RENURE criteria for each Member State (without additional regional conditions).
- Incentives are needed to stimulate the greater use of recovered mineral fertilisers to meet with the crop requirements and without causing environmental pollution.
- If with time it is shown that incentives alone are insufficient, stricter limits should be applied to the direct application of untreated, low nitrogen fertiliser replacement value (NFRV) raw manure and digestate onto agricultural land.
- There needs to be strict monitoring of the amounts of RENURE produced and used on agricultural land.

SYSTEMIC has shown that several products produced in demonstration plants and outreach plants achieve high nutrient replacement values. These products can prove to be compliant with the FPR and/or with RENURE criteria. In addition, they can save greenhouse gas emissions if replacing conventional mineral nitrogen fertilisers. This opens an opportunity for rewarding farmers / biogas plant operators by carbon credits if the European Emission Trading System is extended to biogas operators. This could be covered by legislation pertinent to the Fit for 55 Package of the European Green Deal, presented in the communication (COM(2019)640) of 11 December 2019.

It is the opinion of SYSTEMIC that unless clear policy steps are taken, both to address barriers to the uptake of nutrient recovery and reuse, and to provide incentives for the sector, a level playing field will not be met for the nutrient products (biobased fertilisers). Without a level playing field for these biobased fertilisers vis a vis synthetic fertilisers, that sector will struggle to retain financial viability, and investment will be hard to access, thus the recovery and reuse of nutrients in Europe will remain limited.



10. Way forward

Apart from technical readiness and cost-efficiency of producing biobased fertilisers from digestates at large scale demonstration biogas plants, farmer awareness and acceptance of recovered nutrient products is essential to obtain revenues from them. To obtain this, biogas plants must produce well-defined biobased fertilisers and soil improvers that are in line with the end-users' demands. Even so, the acceptance of recovered biobased products requires market development, no legislative barriers, an equal playing field, and a financial support scheme due to the direct contribution to the goals of the European Green Deal.

Nowadays, farmers are only prepared to pay a lower price for recovered nitrogen rich liquid products, compared to conventional fertilisers, because there are also higher logistical costs due to the lower nutrient content of biobased fertilisers (transport costs of the larger volume) and (possibly) adapted spreading equipment required. Additionally, the biobased products are often unfamiliar, farmers do not trust the nutrient uptake efficiency by different crops, yet. For solid products, pellets are preferred and tailor-made nutrient ratios and high organic matter content are valued more. The latter is valued for its contribution to soil quality and fertility, but the prices on the market are still low.

Demonstration of the use of biobased fertilisers by showing the application technology and agronomic performance in practice, will help to overcome the resistance to use biobased products. To really create revenues for plant operators producing biobased fertilisers, an advanced market strategy has to be developed aimed at a certain buyer group: (organic) farmers, retailers, private gardeners, or even the mineral fertiliser industry. By engaging with farmers in the nearby region, consultants and technology developers (e.g. adjusted application machinery), retailers, etc. will contribute to a higher acceptance towards the recovered nutrient products as shown in Italy (Acqua & Sole) and the Netherlands (Groot Zevert Vergisting).

SYSTEMIC has demonstrated that recovery of nutrients and production of nutrient fertilisers can be worthy alternatives for replacing conventional fertilisers. Biogas plants are increasingly becoming the producers of valuable fertilisers with a lower CO_2 footprint. The market for this type of products is still young and needs to be further developed. The next steps are identified as follows:

- Biogas plant owners need to develop better strategies to meet with the demand for products (farmers) in the region where they are operating.

- Farmers, as main end-users, should work together with biogas plants owners, who produce new nutrient fertiliser products, in order to get practical experiences with these type of fertilisers in their own region and to collect data on the agronomic and environmental performance of the products. Regional authorities should facilitate this process, especially in terms of minimizing legislative barriers.

- Fertiliser manufactures have to develop new strategies to use these types of biobased fertilisers as resources for production of conventional and biobased fertilisers.

- The EU needs to develop a clear legal framework that ensures an equal playing field together with a financial support scheme based on emissions avoided by producing and using recovered nutrients from organic waste and residues streams as fertiliser: e.g. via extension of the European Emission Trading System to biogas operators.

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To ensure the open access of the deliverables of the SYSTEMIC project, all public deliverables will be available, even after the end of the project, via the library of Wageningen University and Research (https://www.wur.nl/en/Library.htm) and also via digital platform Biorefine Cluster Europe (https://www.biorefine.eu) and websites of some of the partners (https://www.vcm-mestverwerking.be/en/faq/3921/systemic). The full reports can be found at www.systemicproject.eu/downloads under "Project Deliverables".

SYSTEMIC
Circular solutions for biowaste

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Systemic large-scale eco-innovation to advance circular economy and mineral recovery from organic waste in Europe

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