Cover Delivery Report

Title of the Deliverable:	**Market Research in Europe**
WP Title and Number:	**WP3, D3.4**
Date of completion:	**26 February 2021**
First Author:	**Marieke Verbeke**
Co-author(s):	**Ludwig Hermann, Oscar Schoumans, Inge Regelink**
Name of the responsible WP Leader:	**Marieke Verbeke**
Date of approval by the Coordinator	**26-02-2021**

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 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 years.

SYSTEMIC

Circular solutions for biowaste

2020

Market research in Europe

Verbeke M, Hermann L., Regelink, I.C., Schoumans, O. F.

Vlaams Coördinatiecentrum Mestverwerking vzw

Bruges, February 2021

Document type: Public Report

Deliverable D3.4

Horizon 2020

History of changes

Date	Version	Changes	Page
28-02-2020	1		
26-02-2020	2	Chapter 2.2 added	12-19
		Updated 3.1.5 SAFEMANURE	21
		3.2 End user preferences: -Added data from (Power and Egan 2020) -Added sub-chapters per stakeholder group -Added conclusion	22-34
		Added 4.3 Fertilisers for organic farming	35-41
		Waterleau New Energy removed from section 6.1Biogas Bree, Flanders, Belgium, as it is now a Demo Plant instead of an Outreach Location.	48
		6.4 Greencreate W2V/RIKA Biofuels, Kent, United Kingdom has been added, since they changed from Demo Plant to Outreach Location in 2020.	50
		ANNEX II: Gardening products, soil substrates, Fertilisers for organic farming moved to separate chapter (5)	47-48 Moved to page 34
		ANNEX I: product characteristics removed. Separate fact sheets on the products are made.	40-46
		ANNEX II renamed ANNEX I, ANNEX III renamed ANNEX II	59 66

Content

Preface

Within the H2020 SYSTEMIC project (Grant Agreement no. 730400) one of the major aims is to explore the possibilities to enlarge the lifetime of available nutrients in biowaste, like manure, sewage sludge, and food- and feed waste streams, in order to meet with the goals of the Circular Economy Package. Besides demonstrating innovative nutrient recovery technologies at large scale biogas plants (5 pioneers), also ten Outreach Locations and twenty-eight Associated Plants from all over Europe are following the performance and business opportunities of the demonstration plants and are interested in the opportunities for their own business case ('first followers'). Each individual biogas plant interested in nutrient recovery and reuse technologies (NRR) should make nutrient products, which meet with the crop requirements in their own region in case they want to apply the products directly on agricultural land. Another possible outcome for these products is to be regarded as secondary resources, which can be used by other industries like e.g. mineral or organo-mineral fertiliser industry.

In order to facilitate implementation of NRR technology at biogas plants, interested in NRR technology a market study was carried out to inspire and inform them about the market opportunities of different types of recovered nutrient products from digestate with current technologies. In addition, a SYSTEMIC nutrient recovery calculation tool (NUTRICAS) has been developed[1], which can be used to estimate the product quality of recovered products of more than twenty NRR cascades, taking into account the specific composition of the digestate of a biogas plant.

Both the market study as well as the NUTRICAS Tool will help biogas plants take the first steps in designing their own specific business case with NRR.

Yet, marketing of new products is difficult for a number of reasons: product characteristics don't meet with consumer's expectations, little is known about the risks and safe use of the products and many biogas plant owners have no training in marketing digestate and consider this not the main focus of their business.

Moreover, end users have specific demands related to new nutrient products, especially regarding the requirements (specs) on delivery (quality, volume, logistics).

The SYSTEMIC consortium hopes that this report will help biogas plants in finding solutions for their own business case in making products which have value in their own region.

We would like to acknowledge the plant owners and staff of Acqua & Sole, AM-Power, BENAS-GNS, RIKA/Fridays, Groot Zevert Vergisting and the 10 Outreach Locations whom delivered information and insights on the marketing of their end products.

The authors

---

[1] NUTRICAS Tool can be found on https://systemicproject.eu/business-development-package/ from 1st April 2021. 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)

Summary

In the SYSTEMIC project, currently 35 European biogas plants are involved as Demonstration Plants, Outreach Locations and Associated Plants. To illustrate which technologies commonly used, the technologies used to treat their digestate and the produced end products are listed per plant.

In the following chapter (2), the nutrient demand in different regions in Europe is discussed, depending on the soil nutrient status, livestock density and available manure, regional legislation, crop cultivation and artificial fertiliser use. Here, for specific regions recovered nutrient products are suggested that would have a high value in replacing mineral fertiliser complementary to base fertilisation with manure or raw digestate.

Next, the framework conditions regarding the marketing of recovered nutrient products are discussed. Legislative aspects are elaborately treated because they have the potential to open of the existing fertiliser market for these new recovered products and generate value for their producers.

The conditions, requirements, specifications, preferences that different end users have for these products are covered for farmers, mineral fertiliser industries and home gardeners. It involves product characteristics like form, composition, contaminant content and volume.

For these 3 types of end users, the following chapter sets out some specific tips for communication and advertising strategy of these products. Special attention is given to some actions that could help boost the product's marketability.

The last chapter describes for each SYSTEMIC Outreach Location recovered nutrient products that could have market potential in their region.

In the first annex, some niche markets for recovered nutrient products as discussed. It includes both current and future potential niche markets and describes the barriers still to overcome before recovered nutrients can be successfully made available on these markets.

The report ends with a positive note: success stories of biogas plants recovering nutrients and stimulating collaborations are described to encourage biogas plants that NRR can be a part of a profitable business case.

Abbreviations

MAP: Manure Action Plan (Flanders)
FPR: Fertilising Products Regulation
P salts: phosphate salts
EGTOP: Expert Group for Technical advice in Organic Production
JRC: Joint Research Centre
DG: Directorate General
LF: liquid fraction

1 Recovered products from digestate

In the SYSTEMIC project, currently 35 European biogas plants are involved. Some of them have already implemented technologies to recover nutrients, organic matter or water from their digestate. These plants are listed in Table 1-1, together with the products they produce. For some of them, the story behind the marketing of their products is described in ANNEX II.

The input streams of the digesters vary between plants and sometimes within one plant over the years. Often, manure, sewage sludge, bio-waste or slaughterhouse waste is used as main feedstock. All these feedstock types have different compositions and therefore also affect the composition of the digestate. The NRR technologies create new products from this digestate, that could have a higher marketing potential or are more easier to dispose of.

General product characterisations for precipitated phosphate salts, mineral concentrates, solid fraction, calcium carbonate, fibres and purified water can be found in the product fact sheets[2]. For the Demonstration Plants, more information about their process and products is available in the SYSTEMIC Factsheets on Demonstration Plants[2]. More detailed information will become publicly available in the form of report D1.13 Final document on product characteristics, lab results and field trials, and report D1.5 on mass and energy balances, product composition and quality and overall technical performance of the demonstration plants[2]. For outreach plants, more information is online available in the SYSTEMIC factsheets for Outreach Locations[2].

Table 1-1. Digestate processing steps and end products of biogas plants involved in SYSTEMIC as Demonstration Plant, Outreach Location or Associated Plant

Biogas Plant	SYSTEMIC Plant	Country	Process steps	Product
Groot Zevert Vergisting	Demonstration Plant	The Netherlands	Centrifuge DAF Micro filtration Reversed osmosis Re-P-eat	NK-concentrate Dischargeable water P-fertiliser (P-salts) Low-P soil conditioner
AMPower	Demonstration Plant	Belgium	Centrifuge Evaporator Reversed osmosis Dryer Acid air scrubber	Permeate Dried solid fraction Ammonium sulphate
Aqua e Sole	Demonstration Plant	Italy	Ammonia stripper/scrubber	Ammonium sulphate Digestate (low in N)
Benas	Demonstration Plant	Germany	FiberPlus® system	Ammonium sulphate Calcium carbonate Fibres Digestate (low in N)

[2] Fact sheets and Deliverables are available https://systemicproject.eu/downloads/. 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)

Biogas Plant	**SYSTEMIC Plant**	**Country**	**Process steps**	**Product**
Waterleau New Energy	Demonstration Plant	Belgium	Centrifuge Dryer Nitrification-denitrification Evaporator Reversed osmosis	 Dried solid fraction Permeate (process water) Concentrated N(PK)
SCRL Kessler	Outreach Location	Belgium	Screw press Dryer	Solid fraction Liquid fraction Dried digestate
GMB	Outreach Location	The Netherlands	Centrifuge Nitrification-denitrification Composting Acid air scrubbing	 Dischargeable effluent Composted solid fraction Ammonium sulphate
Emeraude Bioénergie	Outreach Location	France	Centrifuge Ammonia stripper-scrubber Nitrification-denitrification Dryer	 Ammonium sulphate dischargeable effluent dried solid fraction
Waternet	Outreach Location	The Netherlands	Struvite precipitation Centrifuge Nitrification-denitrification	Struvite Solid fraction (incinerated) Dischargeable effluent
Biogas Bree	Outreach Location	Belgium	Centrifuge Drying Air stripping-acid scrubbing	Liquid fraction Solid fraction Dried digestate Ammonium sulphate
Greenlogix Bioenergy	Associated Plant	Belgium	Centrifuge Lime softener Ammonia stripper-scrubber Nitrification-denitrification centrifuge	Solid fraction Ammonium sulphate Dischargeable water Solid fraction MBR sludge
NDM	Associated Plant	Germany	Screw press Acid air washer Centrifuge Dryer Incineration CO2 stripper Ammonia stripper-scrubber	Solid fraction manure Ammonium sulphate Liquid fraction (NPK fertiliser) P-rich ashes Ammonium sulphate
Agro Energy Hohenlohe	Associated Plant	Germany	Screw press acidification Drying greenhouse pelletizer	 Pelletized dried solid fraction
Suiker unie Dinteloord	Associated Plant	The Netherlands	Centrifuge Nitrification-denitrification	Solid fraction Dischargeable effluent
AFBI	Associated Plant	Northern Ireland (UK)	Screw press and centrifuge	Solid fraction Liquid fraction
Bioenergy Neukirchen	Associated Plant	Germany	Screw press	Solid fraction Liquid fraction
Lüleburgaz, Agman Inc.	Associated Plant	Turkey	Sedimentation pond	Sedimented solids Digestate

Biogas Plant	**SYSTEMIC Plant**	**Country**	**Process steps**	**Product**
IVVO	Associated Plant	Belgium	Screw press Composting Nitrification-denitrification evaporation	 Composted solid fraction Ammonia water Process water
Grupo Biogas Fuel-cell	Associated Plant	Spain	Separation	Solid fraction Liquid fraction
Camposampiero, ETRA	Associated Plant	Italy	Centrifuge Nitrification-denitrification	Solid fraction Effluent
Arbio	Associated Plant	Belgium	Belt press -Nitrification-denitrification -decantation tank Filters Reversed osmosis -dryer Mixing with NK concentrate pelletizer	 Effluent Permeate (irrigation water) NPK pellets
Group Op de Beeck	Associated Plant	Belgium	Centrifuge Composting Evaporator Nitrification-denitrification	 Composted solid fraction Ammonia water process water dischargeable water
Stormossen	Associated Plant	Finland	Centrifuge Nitrification-denitrification Composting	 Dischargeable effluent Composted solid fraction
BioStorg	Associated Plant	Belgium	DAF Belt press composting evaporator	 Composted solid fraction Ammonia water KP concentrate

2 Demand for (recovered) nutrients

The demand for nutrients differs from region to region due to the agricultural landscape (crop distribution and rotation) and the nutrient availability in terms of soil fertility status and livestock density (manure production, use, processing, import and export) and artificial fertiliser use.

2.1 Crop demand

To meet with the nutrient demand of a specific crop, farmers are advised to have a standard soil analysis done to determine their soil nutrient status. Based on this analysis a fertilisation recommendation is given. This fertilisation advice states the amounts of N, P, K, and other elements required for the specific (combination of) crop, soil type including the nutrient status, and allowed maximum application rates according to legislation. Table 2-1 shows some crop specific nutrient administration recommendations or limits. These limits for manure-derived nutrients are 170 kg N ha^{-1} $year^{-1}$ in Nitrate Vulnerable Zones or other limits described in country specific Action Plans (art.3.5 of the Nitrate Directive) (Figure 2-1). In some EU countries (like NL, DE, IE, FL-BE), through a derogation, farmers are allowed to apply more nitrogen from animal manure (e.g. derogation on grassland 230 to 250 kg animal manure derived N/ha/year).
The advised amounts of nutrients will often first be supplied with (digested or co-digested) animal manure, since this is a cheap source of nutrients, especially in regions with high livestock density (Figure 2-3). However, the ratio of N : P : K in animal manure does not exactly fit with crop needs and/or legislative application limits. Therefore, mineral fertilisers are used to fill in the remaining nutrient demand as base fertilisation or additionally during the growing season.

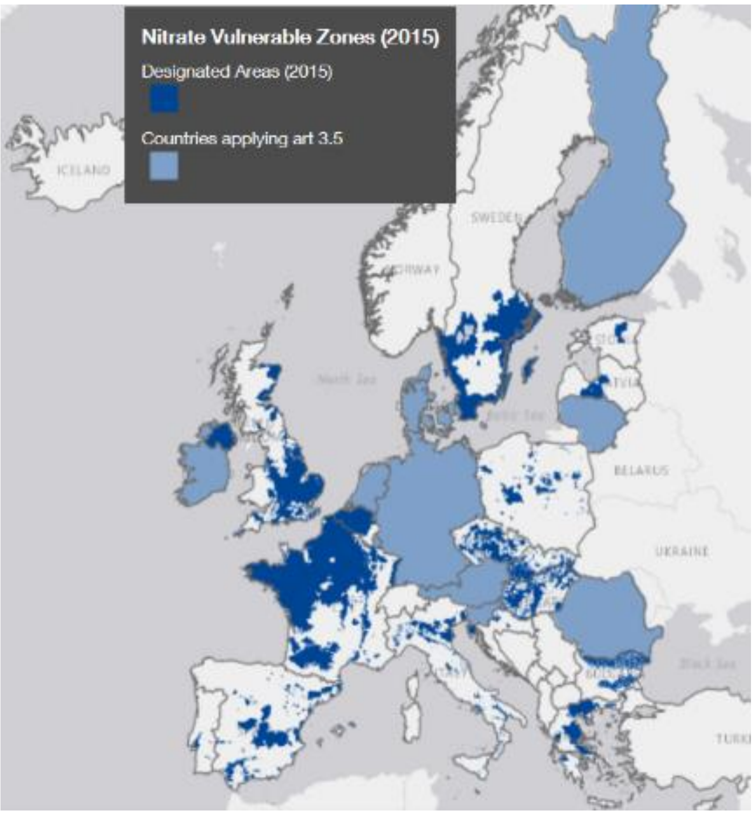


Figure 2-1 Nitrate Vulnerable Zones in Europe (https://water.jrc.ec.europa.eu/portal/apps/webappviewer/index.html?id=d651ecd9f5774080aad738958906b51b)

The potential opportunities of reuse of recovered nutrient products lies in the fact that they can replace equivalent volumes of mineral fertiliser and therefore it can be stated that the demand for nutrients from recycling exists everywhere. Single nutrient fertilisers have a high potential value in situations where they can fill in a gap of a certain specific nutrient. Products with custom-made nutrient ratios fully in line with the crop demand will therefore have to prove to have the highest potential to be used.

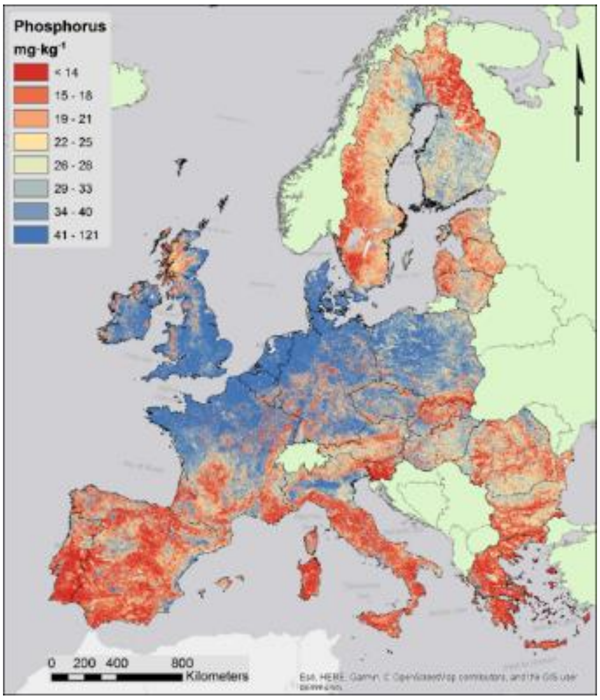


Figure 2-3 Phosphorus in the topsoil in Europe (LUCAS 2009/2012 topsoil data)

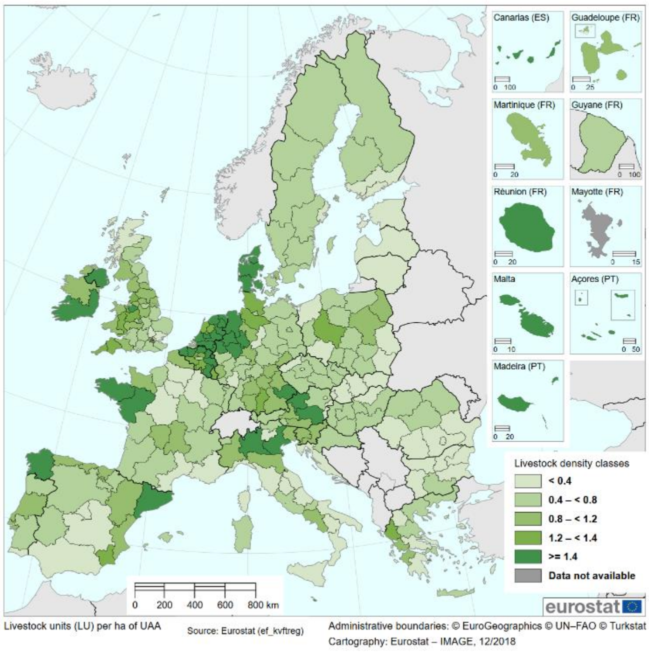


Figure 2-3 Livestock density in units per hectare of utilised agricultural area: cropland + grassland (UAA) (Eurostat: Livestock density by NUTS 2 regions, EU-28, 2016)

In order to map the nutrient demand in different regions in Europe, the most prominently grown crops in Europe have to be determined. For crop production three main types can be distinguished: grassland, cereal and root crops like sugar beets and potatoes (Harms et al. 2019). Figure 2-4, Figure 2-5, Figure 2-6 and Figure 2-7 show how much of the utilised agricultural area: cropland + grassland is occupied by these crops in different regions in Europe and Table 2-1 shows the crop specific N, P and K requirements.

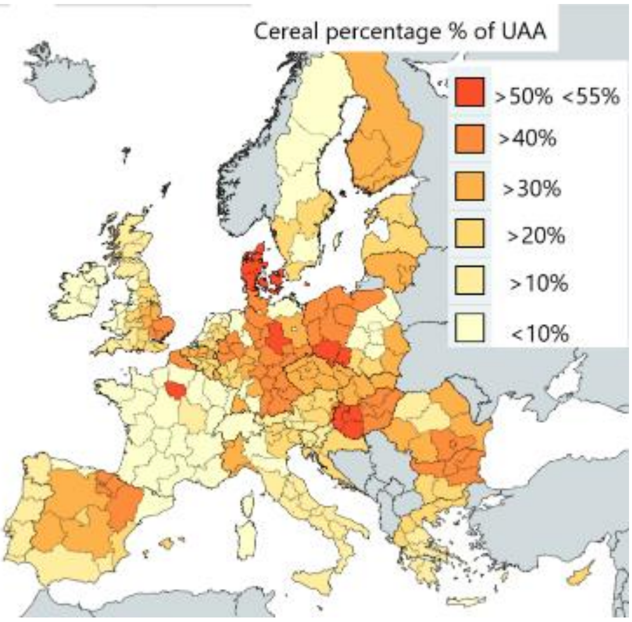


Figure 2-4 Cereals as percentage of UAA(utilised agricultural area: cropland + grassland) (Eurostat: Land cover overview by NUTS 2 regions, type of landcover % [lan_lcv_ovw], 2015)

Cereal regions

Cereals like winter wheat require a fertiliser with concentrated N and no to very little P and K (Table 2-1)(Harms et al. 2019).

In cereal regions with a high P soil status and high manure availability, such as in Denmark, North-West Germany, as well as in the Netherlands and in Flanders (*Figure 2-3* and Figure 2-3), products like scrubber salts (ammonium nitrate and ammonium sulphate) can be regarded as single nutrient fertilisers (few P or K present) and because they have nutrient use efficiencies of around 80% of mineral N fertilisers (Huygens et al. 2019).

The product can be applied as a starter fertilisation or to complement the base fertilisation up to the level for mineral fertilisers in spring and summer (Vaneeckhaute 2015). Ammonium sulphate is also widely used for chickpeas, both for fertigation and for direct soil application for horticulture (Decaluwe 2016).
When using ammonium sulphate, sulphur can still be the limiting factor for application. Therefore, usually a maximum of 1-2 tonne ammonium sulphate per ha is recommended, because a higher sulphur dosing can cause leaching which is harmful for the environment and for drinking water. For ammonium sulphate maximum dosages of 1 – 2 m^3/ha are advised (Agreon 2013; Dieleman 2014; Knuivers 2013; Oost 2009).
North and Central France, Sachsen Anhalt (DE), South West Poland, Hungary, South Bulgaria as well as South-East UK, are cereal regions with low animal manure availability. Most of these soils have high P concentrations, yet this phosphorus is only slowly or not available (complexed in the soil). Ca/Mg-P precipitates could be applied as alternative to mineral P up to the maximum allowable level for P fertilisation. Nitrogen is the limiting factor for fertiliser application. Struvite may provide a source of slow-release N and P (Vaneeckhaute 2015). Also P-rich solid fractions (locally available or imported from P-rich regions) or NPK concentrates from membrane filtration could be used. However, for these products, the N content also has to be taken in account (Vaneeckhaute 2015).
In Southwest Germany soils are less P saturated (in Bulgaria there is even a P deficit), therefore a slightly higher demand for P and K exists here for cereals in comparison to the previously mentioned regions. Here, more of the previously mentioned products could be used, before reaching the P fertilisation limits.

Corn

Corn requires relatively high nitrogen and potassium, with low amounts of phosphorus (Table 2-1). Yet, a start fertilisation with phosphorus is frequently done, although it is only necessary when a soil has a low P content like in corn cultivating regions Hungary, Bulgaria, South of France, East Austria and Romania) and/or an acidic soil or if the early spring was cold and wet (Abts et al. 2016).
Regions cultivating corn, with high P soil status content, are North and West France, Flanders (BE), South of the Netherlands, North Germany and the South of Denmark. Recovered fertilisers could be again scrubber salts and NK-concentrates from membrane technology.
All these corn regions fall partially or completely under the Nitrate Vulnerable zones and therefore, the amount of manure derived N also has to be taken in account when setting up a fertilisation plan.

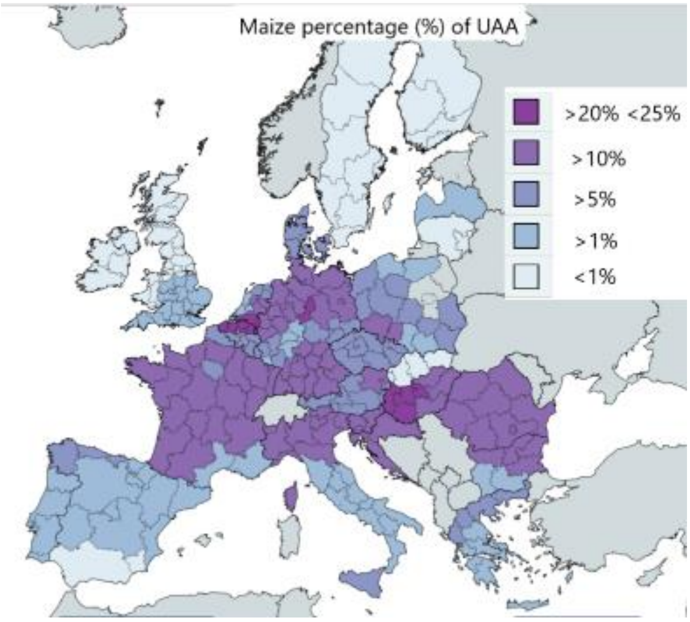


Figure 2-5 Maize as percentage of UAA(utilised agricultural area: cropland + grassland) (Eurostat: Land cover overview by NUTS 2 regions, type of landcover % [lan_lcv_ovw], 2015)

Grass

Grass requires substantial amounts of N (in spring and summer), potassium and sulphur (Table 2-1). In all grassland rich regions (Figure 2-6) NKS blends or ammonium sulphate could replace mineral fertilisers because they combine all nutrients required (Bussink and van Dijk 2011b; Dijkstra et al. 2012; Rombouts et al. 2014).
When the grass is mowed, 60 - 70 kg SO_3/ha is recommended before first cut. Again, a maximum of 1-2 tonne ammonium sulphate/ per ha is recommended to prevent leaching. Less K supplementation is needed when the grassland is grazed because of K supplementation from animal urine (Abts et al. 2016).
Grassland regions in Ireland, when compared to other parts of Europe, have a relatively low demand for all nutrients due to extensive management. This results in low level of fertiliser recommendations. However, soils are relatively low in P so that a moderate demand for P_2O_5 exists (Harms et al. 2019).

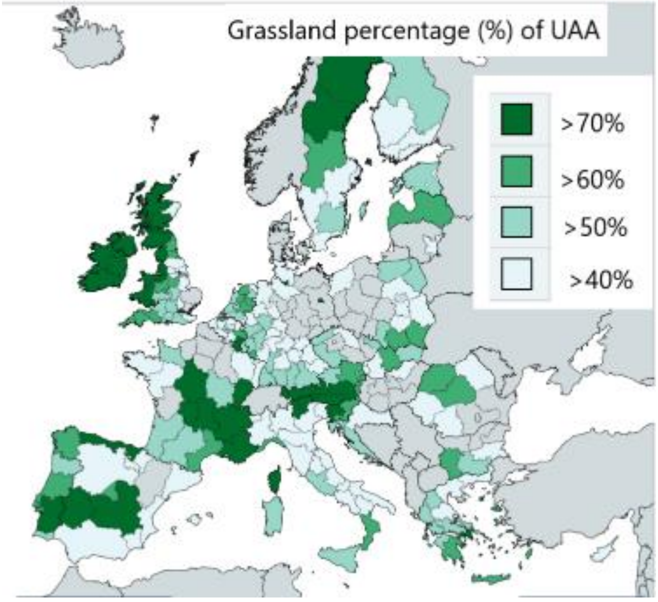


Figure 2-6 Grass as percentage of UAA(utilised agricultural area: cropland + grassland) (Eurostat: Land cover overview by NUTS 2 regions, type of landcover % [lan_lcv_ovw], 2015)

Sugar beets and potatoes

Potatoes are very responsive to P and K and it is necessary to apply these nutrients even in high P soils. Although uptake of P by fodder beet and sugar beet is low compared to N and K, fertiliser P inputs are important because of high response by the beet crop. Sugar beet and potatoes therefore both require a N(P)K fertiliser, for sugar beets the amount of K_2O has to be even higher than for potatoes (Table 2-1). All the P should be applied at sowing time but some of the K can be applied in autumn before (Teagasc, Jonstown Castle, and Environment Research Centre 2016).
NK mineral concentrates or the liquid fraction from digestate could be alternative fertiliser, since all of the regions producing a high share of sugar beets and potatoes are located in livestock intense zones with P rich soils. Only Scotland and South Poland have soils with less P in the toplayer. Solid fraction, struvite or NPK mineral concentrate could have potential in these regions.

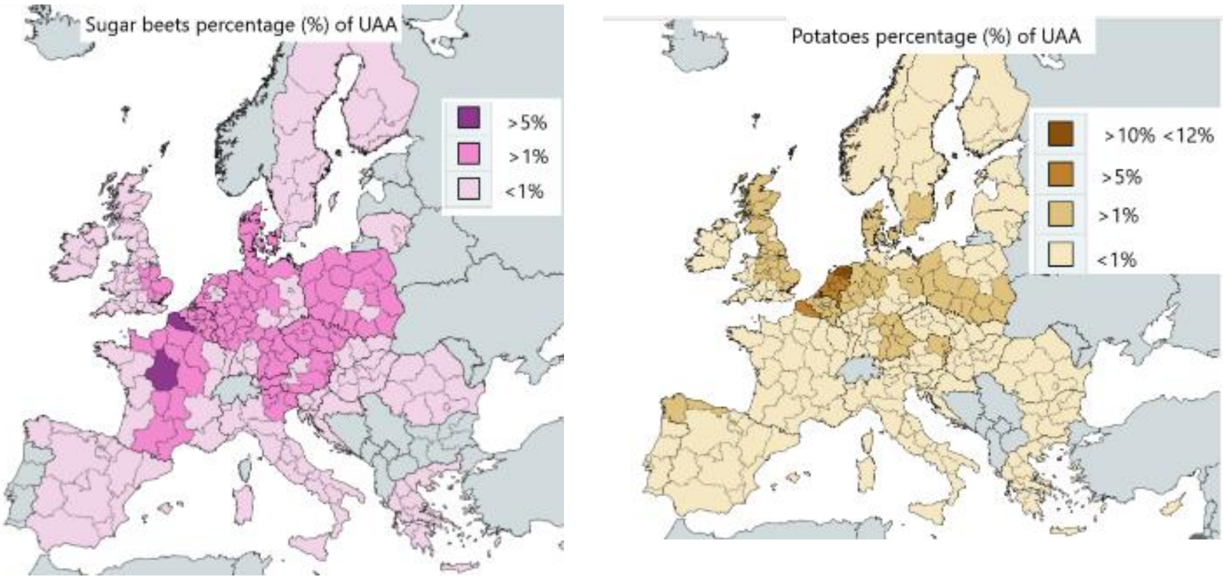


Figure 2-7 Sugar beet (left) and potatoes (right) as percentage of UAA(utilised agricultural area: cropland + grassland) (Eurostat: Land cover overview by NUTS 2 regions, type of landcover % [lan_lcv_ovw], 2015)

Table 2-1. Crop specific nutrient administration recommendations or limits.

Description	Country	Limit/recommendation	N (kg N ha $^{-1}$ year^{-1})	P kg (P_2O_5 ha $^{-1}$ year^{-1})	K (kg K_2O ha $^{-1}$ year^{-1})
Grassland					
Administration for optimal dry matter yield after mowing [1]	BE-Fl	Recommendation	450 kg effective N/ha	100-130	350-400
Administration for optimal dry matter yield after grazing [1]	BE-Fl	Recommendation	325 kg effective N/ha	100-130	
Administration after mowing (Peat, loss, sand, clay) [2]	NL	Application standards	265-345	80-120	
Administration after grazing (Peat, loss, sand, clay) [2]	NL	Application standards	300-385	80-120	
[3]	UK	N-max limit	300		
cereals					
Winter wheat Winter barley Spring wheat Spring barley (on peat, loss, sand, clay) [3]	NL	Application standards	160-245 140 140-150 80	50-120	
Autumn wheat Spring wheat Winter barley Spring barley (on peat, loss, sand, clay) [3]	UK	N-max limit	220 180 180 150		
Winter wheat, assumed yield of 10 kg/ha, soil Index 1-4 [4]	IE	Application standards	100-230 Kg N/ha	0-58 Kg P/ha	0-130 Kg K/ha
Corn, maize					
Administration in June-July (growing stage) for optimal dry matter yield [1]	BE	recommendation	100-180 kg effective N/ha	2 à 3 kg P_2O_5 ha $^{-1}$ day^{-1}	7 kg K_2O ha $^{-1}$ day^{-1}
Soil index 1-4, assuming a dry matter yield of 15 t/ha and not accounting for slurry application [4]	IE	Application standards	75-180 Kg N/ha	20-70 Kg P/ha	120-250 Kg K/ha
Potatoes					
Ware potato Seed potato Starch potato (Peat, loss, sand, clay) [2]	NL	Application standards	188-250 120 184-240	50-120 kg P_2O_5 ha $^{-1}$ year^{-1}	
Main crop Early Seed (soil index 1-4) [4]	IE	Recommendation	95-170 80-155 80-155 Kg N/ha	50-125 50-125 85-125 Kg P/ha	120-305 60-150 65-245 Kg K/ha

Sugar Beets					
Administration in August-November for optimal dry matter yield [1]	BE-Fl	Recommendation	160 kg N/ha	110 kg P_2O_5 /ha	310 kg K2O/ha
(On peat, loss, sand, clay) [2]	NL	Application standards	116-150	50-120	
[3]	UK	N-max limit	120		
soil index 1-4, different rainfall amounts [4]	IE	Recommendation	60-185 Kg N/ha	20-70 Kg P/ha	80-320 Kg K/ha

[1] (Abts et al. 2016)

[2] https://www.rvo.nl/onderwerpen/agrarisch-ondernemen/mestbeleid/mest/tabellen-enpublicaties/tabellen-en-normen 2017

[3] (GOV. UK, Department of Enviroment 2018)

[4] (Teagasc et al. 2016)

https://www.teagasc.ie/crops/soil--soil-fertility/crop-n-p-k-advice

2.2 Use of mineral and organic fertilisers

To guarantee crop yields and food security, mineral and organic fertilisers are used in Europe. The production of nitrogen-based fertiliser uses high amounts of, predominantly, fossil fuel (natural gas and coal) and therefore has a negative impact on the Green House Gas (GHG) balance of the agricultural sector, when included in the measurement.

Ammonia production as such requires large amounts of energy and thereby the process emits carbon dioxide, as well as the next step in the process when ammonia is transformed into urea. However, the average energy efficiency for European fertiliser production plants is higher than the global average due to the use of relatively modern technology and reduced use of natural gas as main energy supply.

However, the use of fertilisers in general makes the plant production more efficient. A higher quantity of output (i.e. grain, grass etc.) can therefore be produced on a smaller surface, which reduces the agricultural area needed (European Commission 2019).

Organic fertilisers

Application of manure or digestate also adds organic matter to the soil next to fertilising nutrients. When produced on livestock farms, manure (or slurry) is applied on cropland and pastures both in conventional and organic production systems. Since 2000, the dairy production has slightly increased but the total number of cattle has decreased and thereby affected the amount of manure produced, which has fallen across the EU (European Commission 2019)(Figure 2-8). No regional data for the use of animal manure were found in Eurostat.

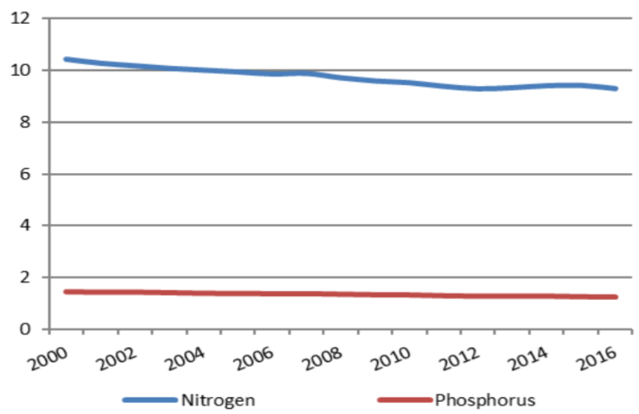


Figure 2-8 Nitrogen and phosphorus input via manure application in the EU (million tonnes/year) Source: Eurostat, (European Commission 2019)

Mineral fertilisers

Fertilizers Europe estimates that, out of the 179 million ha of agricultural land available in the EU, 134 million ha (75 %) are fertilised with mineral fertilisers. Around half of the fertilisers used is applied on cereals (26 % on wheat, 25 % on coarse grains), 16 % on grassland and 11 % on oilseeds. The total volume of fertilisers applied on specialised crops (potatoes, sugar beet, permanent crops) is relatively low. The application rate per hectare varies considerably between different crops. For example, wheat is grown on 15 % of the EU agricultural land but represents 26 % of the fertiliser use, oilseeds are grown on 6 % of the agricultural land but represents 11 % of the fertiliser use, while fertilised grassland represents 18 % of the land use and 16 % of the fertiliser use (European Commission 2019).

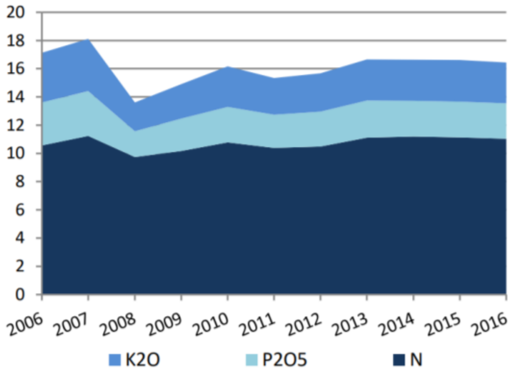


Figure 2-9 Consumption estimates of manufactured fertilisers in the EU (million tonnes/year) Source: DG AGRI, based on Eurostat, (European Commission 2019)

When distinguishing between different types of manufactured fertilisers, nitrogen is by far the most used nutrient in the EU by volume. It represents more than two-thirds of the total use of the three main nutrients (N, P and K). Phosphate and potassium are applied in lower quantities on EU agricultural land, and represent less than 20 % each of the overall use in volume (European Commission 2019).

Consumption estimates of manufactured fertilisers are stable across the EU while diverging trends are occurring in the EU-15 and the EU-N13. In Member States which joined the EU after 2004 (EU-N13), a rising trend is observed but starting from a relatively low level compared to the other Member States (European Commission 2019)(Figure 2-10).

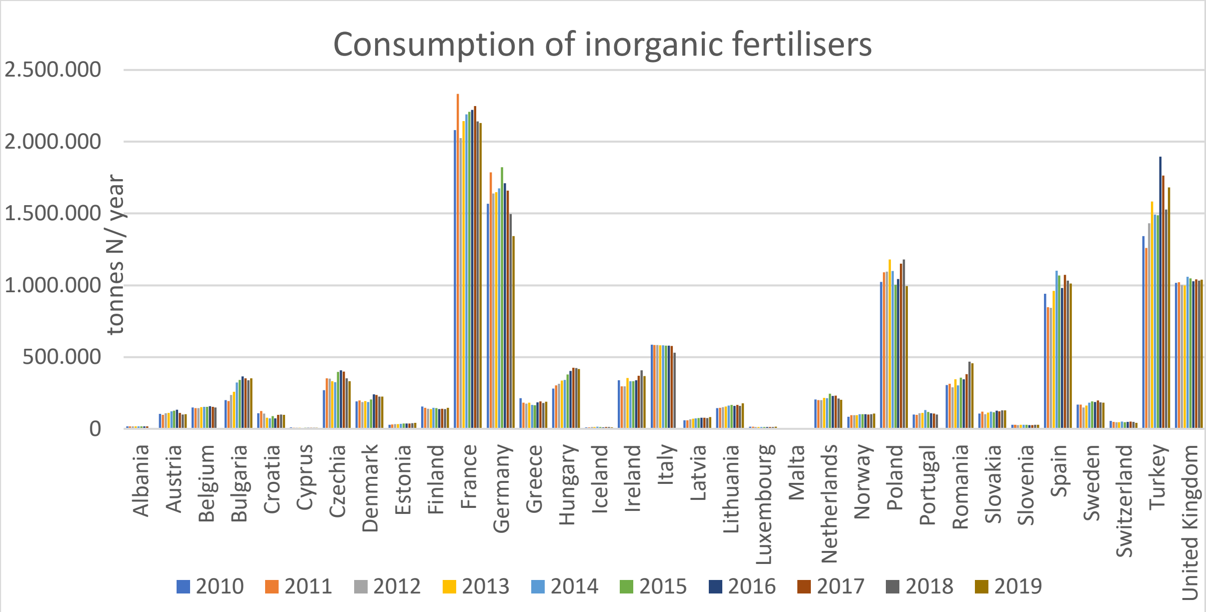
On NUTS 2 region level, for many member states there is no recent data on inorganic fertiliser use (Figure 2-11).

When we would focus on the regions of the SYSTEMIC demo plants and Outreach Locations, only for Bretagne and Catalonia, data were available (Figure 2-12). Both regions have a high livestock density and are located in Nitrate Vulnerable zones, with high P concentrations in the top soil (Figure 2-3). In general, the fertiliser consumption is steady over the years and even decreases slightly in the last 2 years. This suggests that there is land enough land available for spreading organic fertilisers from manure or bio-waste and that not much mineral fertilisers are needed to add the remaining nutrients to reach the crop's needs within the nutrient application limits.

However, no data were available on Eurostat on the use of organic fertilisers from manure or bio-waste or the export or processing of these nutrients. Therefore, this hypothesis could not be confirmed.

Belgium as a member state shows, like many other countries and regions like Bretagne and Catalonia, stable amounts of fertiliser use (Figure 2-10). It is also a region with high livestock density with strict limits for P and animal N application on agricultural land imposed by the Flemish manure decrete and the Manure Action Plan 6. Unfortunately, no regional data are available on Eurostat, however for Flanders (northern part of Belgium) there are detailed data available from the Manure Report (Flemish Land Agency 2020) and the yearly survey on operational capacity of manure processing in Flanders (VCM 2020).

Therefore, the following section will zoom in on this region, trying to unravel the underlying transfer of nutrients from animal manure, bio-waste digestate and manufactured inorganic fertilisers.



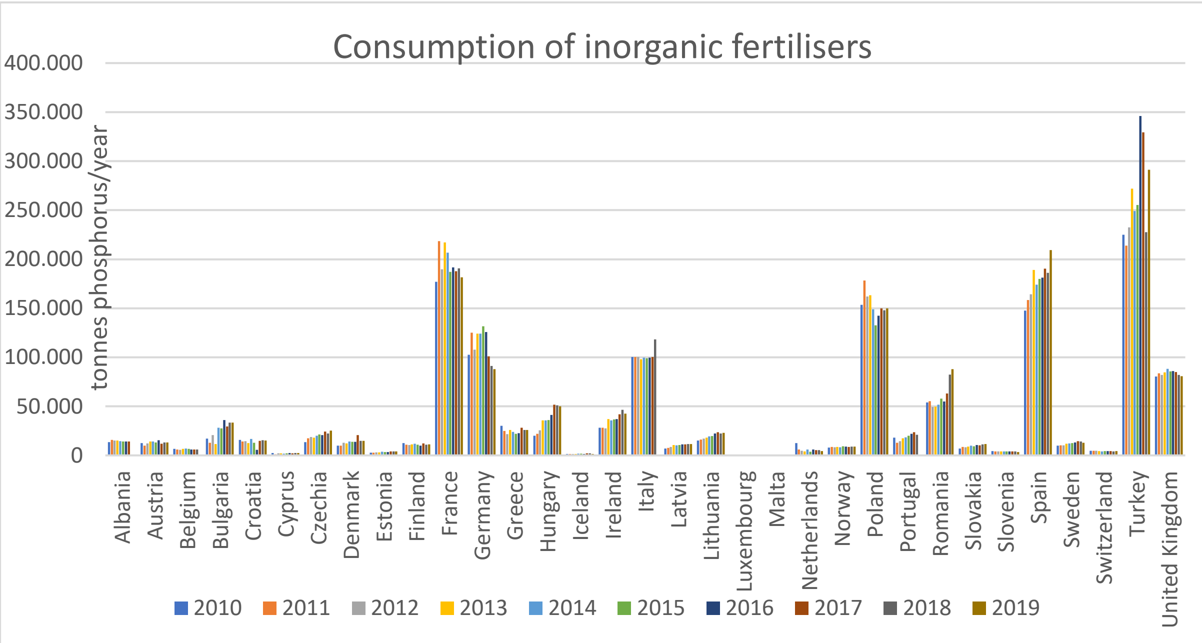


Figure 2-10 Consumption of inorganic fertilisers [AEI_FM_USEFERT]. Eurostat.

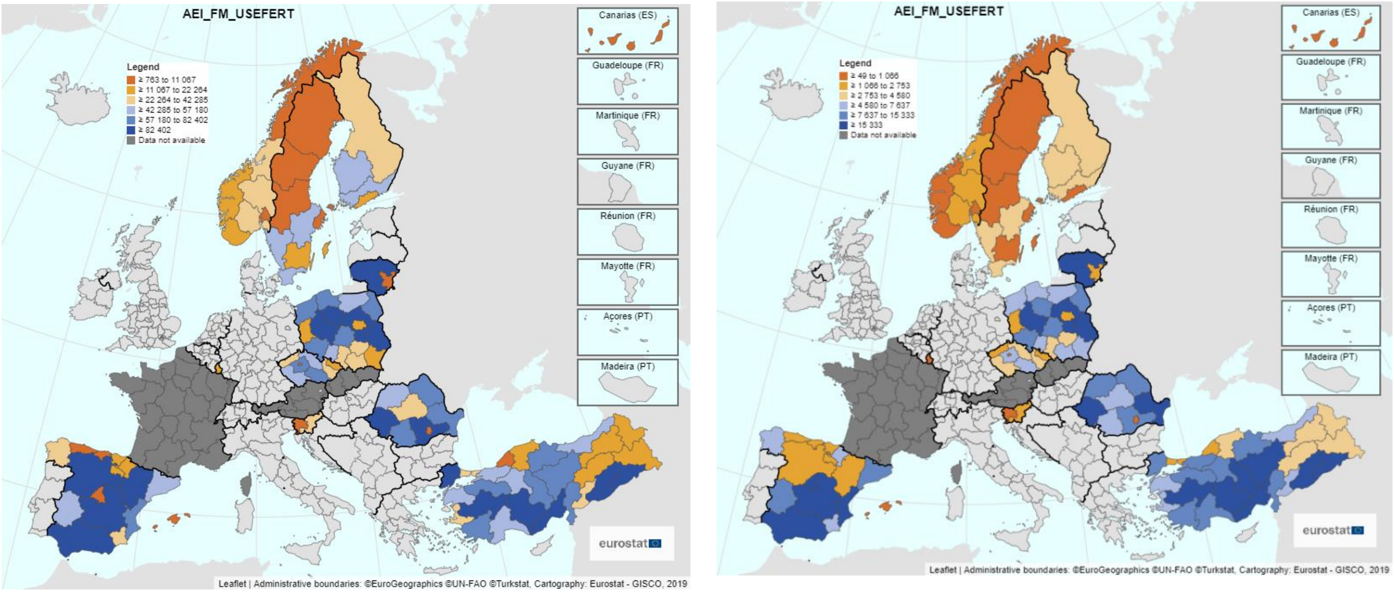


Figure 2-11 The use of inorganic fertilisers in NUTS 2 regions in 2018 (tonnes N/year)(left) and (tonnes P/year) (right) [AEI_FM_USEFERT] Eurostat.

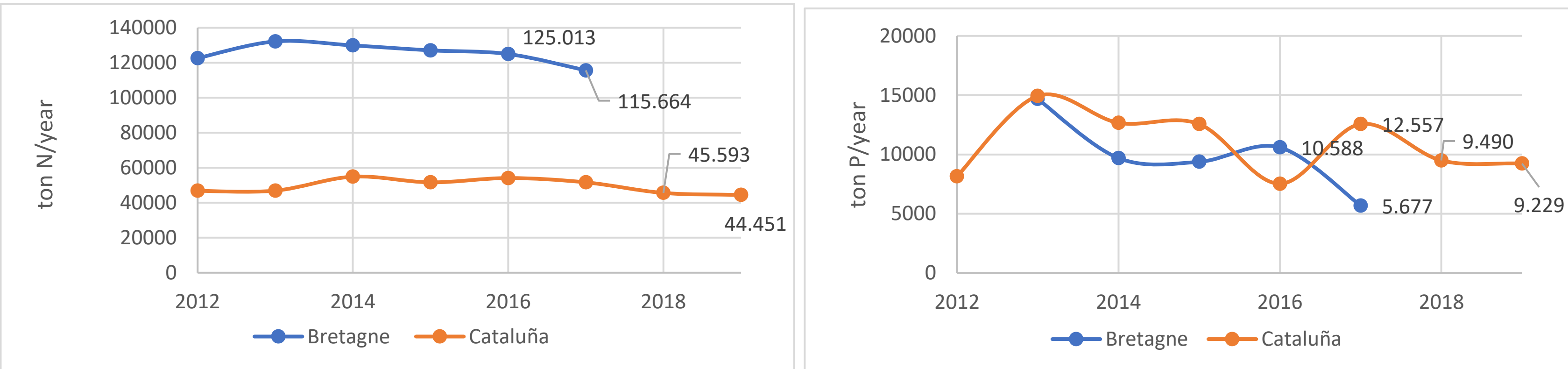


Figure 2-12 Consumption of inorganic fertilisers [AEI_FM_USEFERT] for NUTS2 regions. Eurostat.

Use of mineral and organic fertilisers: close-up on Flanders, Belgium

To be able to comply with the nutrient limits, Flanders has chosen to implement technologies and specific strategies to lower the amounts of N and P ending up on Flemish soil.
In 2019, 49,784 ton of N and 13,161 ton of P from animal manure was processed by means of biological nitrification-denitrification, biothermal drying and export. This was 7,157 tons of N and 3,152 tons of P more than in 2017 (Table 2-2).
This increase could be due to stricter application limits for phosphorus and the spreading regulation in MAPV and MAPVI. Mainly due to an increase in amounts of processed of pig manure (+18%), cattle manure (+15%), poultry manure (+15%). However, only the number of poultry animals has been increasing (+23%), while the numbers of pigs and cattle stayed stable (*Figure 2-13*).
Processing of co-digestate in biological nitrification-denitrification, composting and export has decreased by 240 ton N (-26%) and 12 ton P (-60%) relative to 2017 (Table 2-2).

Table 2-2 Amounts of manure and nutrients processed and amounts of manure, non-manure fertilisers and synthetic fertilisers used on Flemish soil.

[1] **Processing**	2017			2019		
	ton	**kg N**	**kg P**	**ton**	**kg N**	**kg P**
manure	4,314,925	42,601,120	10,009,151	4,955,070	48,995,724	12,884,443
Spent mushroom compost	18,857	120,687	32,887	11,408	73,010	19,895
Raw 'animal' digestate	12,059	79,589	21,031	4,911	32,415	8,565
Liquid fraction digestate	71,979	403,082	0	49,478	277,079	0
Solid fraction digestate	55,782	446,254	291,850	47,483	379,867	248,432
Total manure derived fertilisers	4,314,925	42,601,120	10,009,151	5,068,351	49,758,096	13,161,337
[2] **Use**					2019	
Manure derived fertilisers					92,394,167	17,612,396
Non-manure derived fertilisers					2,859,634	427,760
Synthetic fertilisers					51,961,385	547,370

1 (VCM 2020). Table 17, manure= pig manure, cattle manure, poultry manure, horse manure. 'animal' digestate = digestate from co-digestion

2 (Flemish Land Agency 2020) Table 6: use of animal manure, synthetic fertilisers and other fertilisers on Flemish agricultural soil in 2019. Manure = manure derived products (incl. co-digestate), other = vegetal digestate or other non-animal derived fertilisers

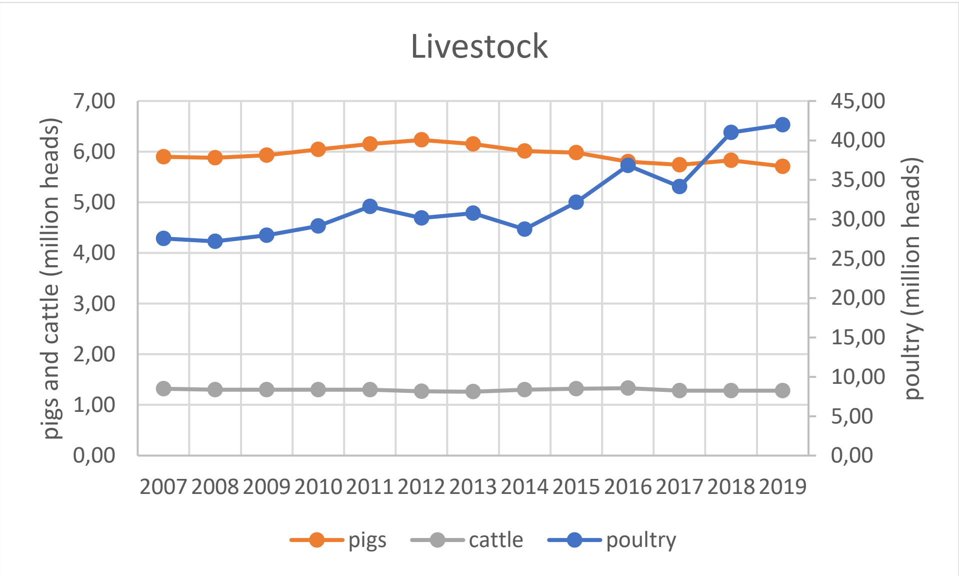


Figure 2-13 Number of livestock in Flanders in (million heads). Source: MIRA based on General Directorate Statistics

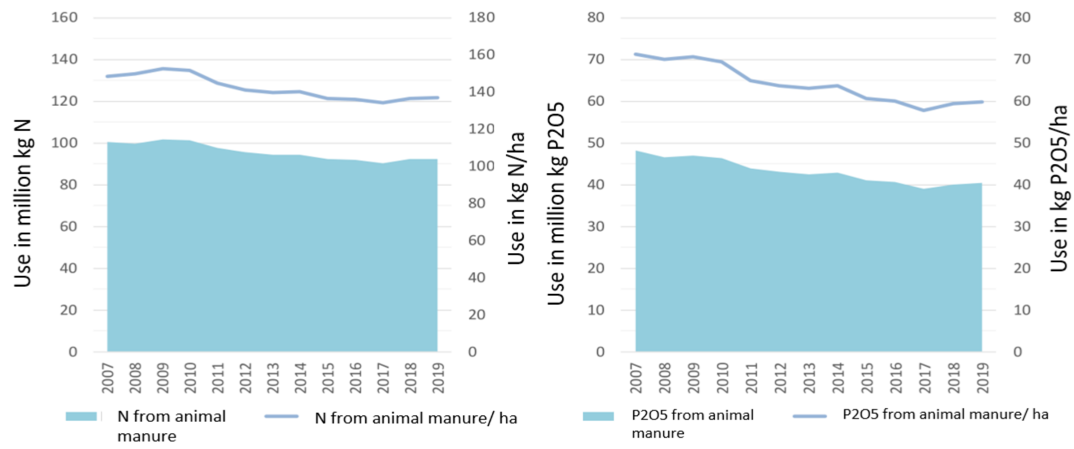


Figure 2-14 Evolution of the use of animal manure derived products in Flanders in 2007-2019. Adapted from: (Flemish Land Agency 2020)

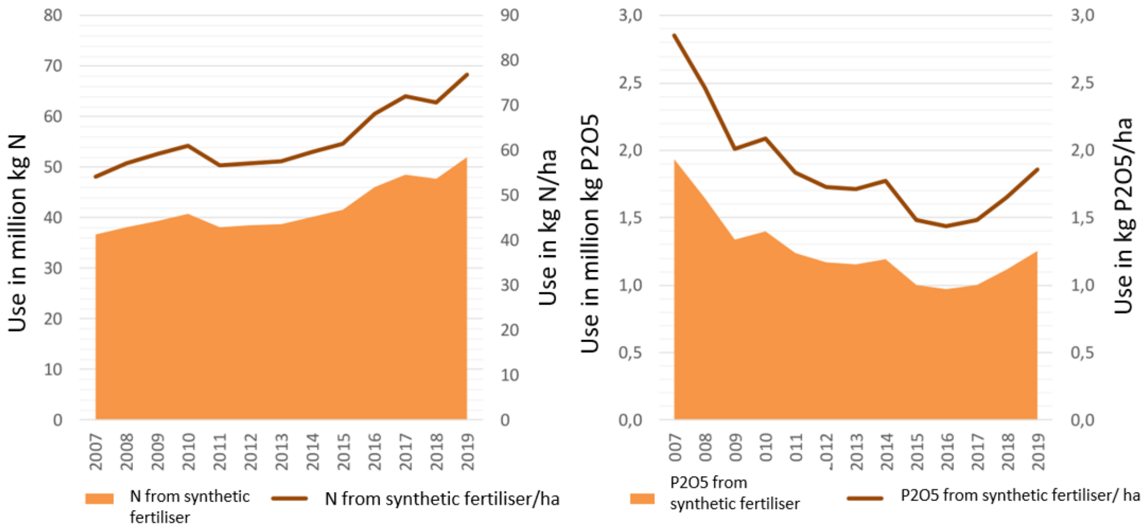


Figure 2-15 Evolution of the use of synthetic fertilisers in Flanders in 2007-2019, based on declaration statements of the farmers at the Manure Bank.

The application of nutrients from animal manure/ha has remained the same (Table 2-2 and Figure 2-14). Figure 2-15 shows that the use of synthetic fertilisers has been increasing in the last 2 years. For N synthetic fertilisers, there has been an increase over the last 10 years of (±55% in kg N/ha), which was not visible on member state level (Figure 2-10).
These data could suggest that in Flanders the surplus of manure derived products renders a steady surplus of nutrients for the region. However, only a limited amount can be spread on Flemish soil because the nutrient ratios in these products are not in line with crop demand and are further constrained by individual N and P limits.
Therefore, the remaining crop nutrient demand (N or P) is supplemented by using synthetic fertilisers, which can be applied above 170 kg N/ha.year in the case of nitrogen. Synthetic fertilisers also combine this advantage with familiarity of products, high nutrient content and stability.
This could suggest that manure derived nutrients are being processed and later added to crops in the form of synthetic fertilisers.

Conclusion

This chapter shows that the demand for nutrients from NRR exists everywhere, even in regions with high livestock density where animal manure is already largely used as a source for nutrients. The potential of these recovered nutrient products lies in replacing volumes of mineral fertilisers (rock phosphate and mined potassium, Haber-Bosch derived nitrogen fertiliser) (Harms et al. 2019).

From a sustainability point of view, many mineral fertiliser producers have been already investing in research and development for replacing ammonia production based on fossil fuel energy with renewable energy. For example, in 2020 Yara announced plans to fully electrify its ammonia plant in Porsgrunn, Norway with the potential to cut 800,000 tonnes of CO2 per annum, equivalent to the emissions from 300,000 passenger cars(Yara 2020). However, recovered fertilisers from bio-waste (digestate, manure) could be locally used and produced with green energy (i.e. anaerobic digestion), which could contribute to a smaller CO_2 footprint (Hermann and Hermann 2020). If these products would have tailor-made nutrient ratios, more nutrients could also be applied and could be taken up by the crops more effectively.

(Harms et al. 2019) have quantified the net potential demand for nutrients and nutrient ratios in recovered bio-fertilisers in North-West Europe. They conclude that the regional demand for nutrients is not only affected by crop cultivation and crop nutrient demand, but also by the regional availability of manure nutrients and the current use of synthetic fertilisers.

However, to create a complete picture of the theoretical replacement potential of recovered nutrients detailed regional information is needed on crop cultivation and the use, processing (incl. import and export) of nutrients of animal manure (derived fertilisers), synthetic fertilisers and other fertilisers.
A lot of other aspects such as legislation, user preferences, safety, applicability, awareness and marketing strategy will determine the use of recovered nutrients in the future. This will be discussed in the following chapters.

3 Framework conditions

3.1 Legislative aspects

If a product will be used directly as fertiliser or as secondary raw material for the production of fertilisers, different European and National rules for marketing and application need to be taken into account.

These legislations came into force to protect the environment and fair trade in the EU. In general it can be stated that the Fertilising Products Regulation, the Waste Framework Directive, REACH and the Nitrate Directive are the most important legislation aspects to accomplish with respect to European market for secondary nutrients and enhance circular economy.

In the following paragraphs, the main regulated aspects posed by of each those legislations are shortly summarized with possible options (already in progress) to facilitate marketing and use. More in depth information on this topic can be found in "D 2.1 Report on regulations governing AD and NRR in EU member states" [3].

3.1.1 European trade of recovered fertilising products

The Fertilising Product Regulation 2003/2003, defines and lists inorganic fertilisers (primary, secondary and micro-nutrients), liming materials and regulates their market placement by establishing criteria to be marketed as a mineral fertiliser in the EU:

- comply with an existing type designation (single or composite) from the Regulation;
- meet the corresponding minimum composition requirements (e.g. 3% N, 5% P_2O_5 and sum at least 15%, depending on the type);
- chemically obtained;
- no addition of organic nutrients of animal or vegetable origin

The existing Fertilising Products Regulation fails to include organic fertiliser products and secondary raw materials which would otherwise be disposed of as waste. Therefore, a new Fertilising Product Regulation has been published (2019/1009) (25th June 2019), replacing the current Fertilising Products Regulation by 16th of July 2022.

The new Fertilising Products Regulation sets out common rules on converting bio-waste into raw materials that can be used to manufacture fertilising products and it defines safety, quality and labelling requirements that all fertilising products need to comply with to be traded freely across the EU. Producers will have to demonstrate that their products meet those requirements, as well as limits for organic contaminants, microbial contaminants and physical impurities before affixing the CE-mark.
The new rules will apply to all types of fertilisers to guarantee the highest levels of soil protection. The Regulation introduces a limit for cadmium in phosphate fertilisers of 60 mg/kg P_2O_5.

As some fertilising products are not produced or traded cross-border in large quantities, the European Commission (EC) is proposing optional harmonisation: depending on their business strategy and type of product, manufacturers can either choose to CE mark their product, making it freely tradable in the single market according to common European rules, or have it traded in one member state according to its national standards. It would also be possible to create a "mutual recognition" agreement with a neighbouring country to market it across the border.
Currently the EC is implementing the different administrative bodies that are needed to have conformity assessment for products, market surveillance, development of methods of analysis for each product etc. On a national level, each member state must appoint certified notifying bodies which will be assessing the products' conformity with the regulation.

The new Regulation has annexes with lists of Component Material Categories (CMC) for CE labelled fertilisers from organic and inorganic materials, i.e. products that have reached the end-of-waste status.
A provision of CMC 10 (Products derived from animal by-products) is foreseen for certain animal by-products like products derived from manure, having reached the end point of the manufacturing chain

[3] https://library.wur.nl/WebQuery/wurpubs/fulltext/476673, www.systemicproject.eu/downloads

(excluding Cat 1 animal by-products). However, until today CMC 10 still needs to be completed because no criteria have been set yet for when products from animal manure have reached an end point in the manufacturing chain ("end-of-manure-status", animal by-products regulation).

3.1.2 Fertiliser application recommendations and limits

Several regions in Europe with intensive livestock farming suffer from excessive concentrations of phosphorus in the soil and nitrates leaching to groundwater and surface water, which must be controlled to prevent eutrophication of water bodies. Excessive potassium application can lead to salination of the soil and increased losses to waters.
To prevent these environmental burdens, national regulations or recommendations are implemented , which often depend on field conditions (crop type, the soil type and the soil nutrient status) (Harms et al. 2019).

Beside different National regulations and recommendations, the Nitrate Directive (91/676/EEC) provides the regulatory framework for protecting ground and surface water from nitrate pollution in nitrate vulnerable zones and have to be implemented within the national law of EU members.

The main protective measure is limiting the application of total N coming from animal manure to 170 kg/ha/year. This also includes recovered nitrogen fertilising products derived from manure, even if they are (agronomically and environmentally) not significantly different from a chemical fertiliser like recovered ammonium sulphate. However, the SAFEMANURE study (performed by JRC in 2018-2020) will give new advices how to deal with such products (see section 3.1.5).

3.1.3 Derogation on application limit of 170 kg N/ha/year

In some EU countries (like NL, DE, IE, FL-BE), it is possible to apply for a derogation, to be able to apply more nitrogen from animal manure (e.g. on grassland 230 to 250 kg animal manure derived N/ha/year). For this, different conditions, like mostly a high share of grassland surface, must be fulfilled. The derogation is re-evaluated after a certain period and is valid for a limited time period.

3.1.4 Pilots in the Netherlands

In the Netherlands, two pilots are running where a different approach is used in order to test the environmental risk and agricultural aspects of recovered N products.
In 2009, some manure processing plants were producing mineral concentrates with membrane technology (all reversed osmosis). The farmers organisation (LTO,) urged the ministry to negotiate with the European Commission conditions under which the mineral concentrates could be used above the limit of 170 kg N/ha/year but within the total N application limit (manure N and mineral N fertiliser) (91/676/EEC).

This was framed in a 2-year pilot project ("Pilot Mineral Concentrates") to investigate the agronomical, economic and environmental aspects of these mineral concentrates from animal manure.
The EC approved the request, under the following conditions:

- Maximum 10 companies [[4]] could were allowed produce the mineral concentrates.
- They are acknowledged as producer via the Implementing Regulation for the Fertilisers Act and use reversed osmosis.
- A group of independent researchers (WUR) provide guidance, conduct field trials and report on the agronomical, economic and environmental aspects.
- The mineral concentrates could only be used on an area of maximum 20.000ha
- The producers and farmers of the pilot have to be registered at the Netherlands Enterprise Agency (RVO.nl) who will monitor the use of mineral concentrate.

After two years, a continuation of the pilot was approved.

- From 2014 onward, the mineral concentrates produced had to comply with quality criteria to continue the pilot testing:
    - Minimum 90% NH_4-N

[4] https://www.rvo.nl/sites/default/files/2019/01/Deelnemende-producenten-onderzoek-mineralen-concentraat.pdf

- Minimum ratio total N:P_2O_5 of 15:1
- Minimum electrical conductivity 50 µS/cm

From 2018 to 2021, the pilot will continue to gather more data on product quality, emissions of pathogens and residues of veterinary medicines in the permeate and to improve the stability of the production process.

In 2017, another pilot (area-oriented "pilot Mineral Fertiliser-free Achterhoek") was set up which will run until 31 December 2021.
The goal of this pilot is to produce recovered nutrient products from manure, digestate, digested wastewater treatment sludge and blend them to custom-made fertilisers with nutrient composition fitted for grass or corn in the region. The amount of added mineral nitrogen in the blend should be as low as possible. This way, surplus application of S and potassium would be avoided, and disposal would be restricted to the region of the Achterhoek, hereby eliminating (long distance) import of fertilisers and export of manure -and digestate products.

- Produced products that can be used or blended are mineral concentrate, ammonium sulphate, ammonium nitrate.
- The recovered products are produced by 2 producers: GMB BioEnergy and Groot Zevert Vergisting or by mineral concentrates from the 10 producers from the pilot mineral concentrates.
- Monitoring quality of products -nutrient levels, contaminants (pathogens, residues of antibiotics)- by independent researchers (WUR).
- 10 users have already registered and maximum 150 users can register at the Netherlands Enterprise Agency (RVO.nl) who will monitor the use of the products.
- The products could only be used on an area of maximum 7500 ha.
- Users using the products of GZV (i.e. manure derived products) can apply these above the limit of 170 kg N/ha.year but within the N application limit (91/676/EEC).

3.1.5 SAFEMANURE

The results of both pilots will contribute to a permanent provision planned to be included in the Nitrate Directive for the use of recovered N-fertilisers from animal manure.
In this regard, the European Commission assigned in 2018 the Joint Research Centre (JRC) to conduct a 2-year study ("SAFEMANURE") to set up criteria for safe use of RENURE (REcovered Nitrogen from manurRE) products in Nitrates Vulnerable Zones above the threshold established by the Nitrates Directive (i.e. 170 kg N ha^{-1} per $year^{-1}$) (91/676/EEC).

The study included a literature study, biogeochemical modelling, analysis and comparative pot- and field tests of different manure products provided by Member States.
Provided products included among others (solid/liquid fractions of) digestate/raw manure, reverse osmosis/mineral concentrates and nitrogen salts recovered from stripping-scrubbing.

As a result, SAFEMANURE suggests criteria related to the composition of the RENURE (Huygens et al. 2020).
More specific: mineral N:TN ratio ≥ 90% or a TOC:TN ratio ≤ 3 and Cu: 300 mg/ kg dry matter, Hg: 1 mg/ kg dry matter and Zn: 800 mg/ kg dry matter. Use-specific criteria are not explicitly mentioned. SAFEMANURE does suggest that Member States should take the necessary provisions so that the timing and application rates of RENURE and other fertilising materials are synchronised with plant NPK requirements, and to prevent and minimise nutrient leaching and run-off losses, e.g. by implementing the use of cover/catch crops if appropriate.

The RENURE products are considered technologically neutral, meaning that any product recovered from manure complying to the criteria would be able to be applied above the threshold established by the Nitrates Directive (91/676/EEC).

During a Stakeholder workshop on 30 January 2020 in Seville, the criteria were discussed with stakeholders from the sector. The final report was published in May 2020 (Huygens et al. 2020) and should guide the Member States to enforce good agricultural management practices to the application of these products (Huygens et al. 2020).

3.2 End user preferences

There are many stakeholders possible that could adopt the use of fertilisers with recovered nutrients. The SYSTEMIC project suggests that to a certain extent these recycled nutrient products could replace mineral fertilisers. To get a better idea in which market segment this replacement potential lies, the end user preferences and/or requirements of certain key stakeholders are analysed in this chapter. (Jensen et al. 2016) described the stakeholder mapping in Figure 3-1.

In this part of the report, the preferences of the primary stakeholders: crop-farmers, horticultural producers (vegetables, ornamentals) and private garden owners are looked at.
This because they have relatively high power, as they are the direct users of alternative sources of nutrients (mineral fertilisers) and have the power to decline the recycled nutrient fertilisers, based on their preferences and the fulfilment of their requirements by the recycled nutrient fertilisers.

The preferences of agricultural consultants as secondary stakeholders are also taken into account because they cannot directly advise crop farmers and therefore influence their interests. They however will base their preferences more on an objective point of view, combining their knowledge on crop demand, environmental impact and safety, and general drivers from the whole stakeholder group of crop farmers.

The requirements of mineral fertiliser industry as secondary stakeholder are also included in this analysis. This is because recycled nutrient fertilisers could also function as secondary resources, hereby directly replacing fossil based nutrients (N, P,K) in the production of of (organo-)mineral fertilisers.
The interest in recycled nutrient fertilisers of all stakeholder groups mentioned is generally low. By analysing their preferences and requirements, recycled nutrient fertilisers could be better finetuned to meet the demand of the market and be better accepted.

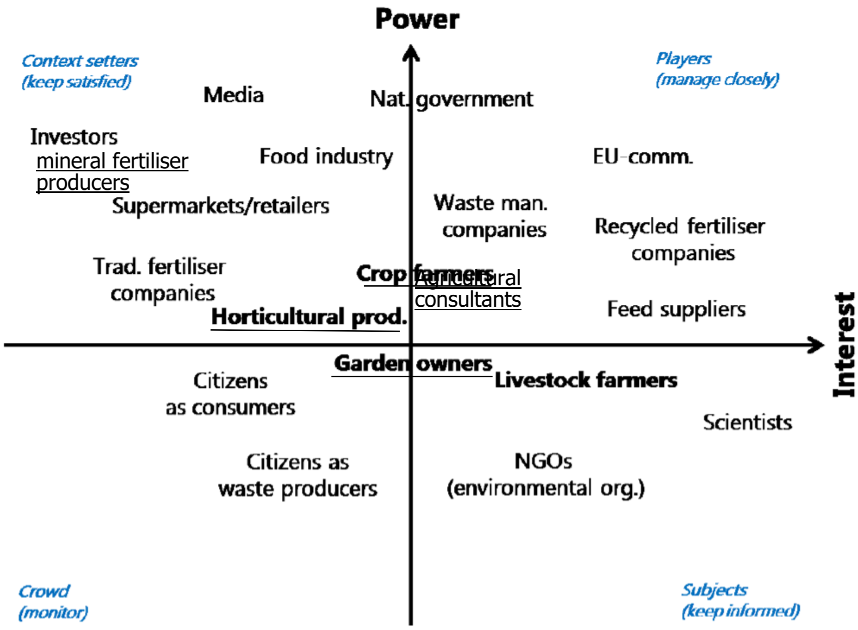


*Figure 3-1 Stakeholder interest-power matrix, with primary stakeholders indicated in **bold**. The stakeholders' whose preferences and/or requirements are analysed in this chapter are underlined. Italicised blue text indicates the four types of stakeholders (according to Ackermann and Eden, 2011, depending on their power and interest and in brackets actions to manage such stakeholders. Adapted from: (Jensen et al. 2016)*

3.2.1 Product quality and composition

3.2.1.1 Nutrient content and ratio

Crop farmers and horticultural producers

Consistency in nutrient content is regarded by producers as necessary to create a standardized product, which builds trust between producer and customer (Dahlin, Herbes, and Nelles 2015).
Unfortunately, the N, P, K concentration of products from digestate can vary largely. This is one of the primary barriers for farmers to use organic fertilisers (Case et al. 2017; Tur-Cardona et al. 2015). Therefore, it is crucial, as a producer of recovered nutrient products, to be transparent about the composition of the product, especially if it doesn't meet fully meet with the criteria of the end users.

When farmers and advisors were asked about the parameters and properties of (recovered) fertilisers, nutrient content, quality and composition were the most frequently occurring responses.
Both farmer and advisor prioritized knowing the nutrient content of the fertilisers over how well the fertilisers work with the plants and in the soil (Dahlin et al. 2016; Power et al. 2019; Power and Egan 2020; Tur-cardona 2015).

There was a difference between the preferences of users that were already familiar with the use of recycled nutrient fertilisers and those that weren't. When having to rank predetermined preferences, "a nutrient ratio that fits with crop nutrient demand" was the number one preference of users of recycled nutrient fertilisers, in particular in Ireland, while non-users only ranked this after price, ease of application and certification (Power and Egan 2020).

Garden owners

For many private customers, it is difficult to assess the quality of a new product. Many gardens are overfertilized suggesting that gardeners don't pay much attention to the nutrient crop demand and if the nutrient composition of the fertiliser matches with this. Results from a choice experiment with German gardeners, indicated that the majority of respondents displayed a "more-is-better" preference for high NPK values (Dahlin et al. 2016). When it comes to soil amendments, many gardeners also don't know the composition (Dahlin, Nelles, and Herbes 2017).
However, it is important that details about nutrient composition and information about product appear on the packaging to guide customers towards environmentally safe use and making informed purchasing decisions (Dahlin et al. 2015).

Mineral fertiliser industry

Mineral fertiliser industries/producers need to comply with strict regulation, guaranteeing a product with constant composition, high purity and stability over time. Table 3-1 gives a rough indication of the quality of recovered nutrient products (as secondary raw material, expected by mineral fertiliser producers. They expect the secondary raw materials to have a similar quality as the primary resources they are currently using, because of the quality standards their customers are currently expecting from the end product.

A constant quality of the secondary raw material is also necessary for a good integration in the production process. Heterogeneous products with variable composition would repeatedly require a constant finetuning of the following process steps. Often the technical boundaries of the systems producing these secondary raw materials from digestate, limit the production of this kind of homogeneous and pure products. If this is the case and constant quality cannot be delivered, the amount of heterogenicity per product and contaminants should be mapped and the error margin should be determined, informing the mineral fertiliser producer of the quality and potential risks for the process.

A better reproducibility of the products could be achieved by finetuning the pre-treatment steps or by adjusting the nutrient content by making blends with products with a more stable concentration like ammonium sulphate, ammonium nitrate, ammonium water or solid fraction. Blending products also fits better to the differentiated demand of the consumers by making high variety of products.

Table 3-1. Indicative concentrations of nutrients in secondary raw materials requested by mineral fertiliser producers. Ntotal= total nitrogen, NH4-N= ammoniacal nitrogen, P2O5=ortho-phosphate, K2O=potassium oxide, DM=dry matter

	Solid secondary raw material [1]	**Liquid secondary raw material** [1]	**Ca-phosphate** [2]	**Struvite**[2]	**P-salts** [3]
Form				>2 mm	Powder or granulates
% solids	-	<3	As high as possible		As high as possible
% Ntotal	>10	>5			
%NH_4-N			Max 30 (3g/kg)		
% P_2O_5	>10	>5	>6 <10, but only if dry product		>9,2
% K_2O	>10	>5			
% DM	>85	-			

Desirable Valuable Mandatory

1 (Brañas and Moran 2016)

2 (personal communication 2018)

3 (Postma et al., 2011)

3.2.1.2 Organic matter

When agricultural land is cultivated intensively organic carbon can be depleted from the soil, because of the removal of organic carbon that has been incorporated in harvested crops.

Manure and other bio-based products containing organic carbon can help replenish this organic matter in the soil, contributing to and improved soil structure, biodiversity and less soil erosion.

In contrast to mineral fertilisers, most recycled nutrient fertilisers from digestate contain organic matter, from which a (large) part does not mineralise during the first year of application (Vannecke, Gorissen, and Vanrespaille 2018; VLACO 2016).

Crop farmers and horticultural producers

Farmers clearly indicated in both studies (Case et al. 2017; Tur-Cardona et al. 2018) that one of the major advantages of recycled nutrient fertilisers products is the content of organic matter/carbon.

In the survey of (Power and Egan 2020) users of recycled nutrient fertilisers ranked high organic matter as the second most important quality, especially in the Netherlands.

Mineral fertiliser industry

In contrast with farmers, mineral fertiliser producers require low levels of organic matter (e.g. carbon) in a secondary raw material especially in combination with nitrate (nitrogen), because carbon can be a catalyst for explosions in N-fertiliser production processes and the combination of high levels of nitrate and organic matter can cause self-ignition. Additionally, the presence of organic matter reduces the efficiency of the polymer added to extract impurities (personal communication, 2017).

3.2.1.3 Pathogens and heavy metals

Crop farmers and horticultural producers

Elimination of germs and bacteria can be achieved through heat treatment, also called hygienisation. This is included in Regulation (EC) 1069/2009 laying down health rules as regards animal by-products and derived products not intended for human consumption, after several severe crises in the food-and feed sector. In the study of (Tur-Cardona et al. 2018), one group of respondents (75% of the respondents) showed positive preferences for hygienisation of the product.

This can indicate that some farmers still believe that products (from manure or organic waste) contain large amounts of animal pathogens or heavy metals. Nonetheless, this is probably only a perception, since analyses on mineral concentrates after membrane filtration of manure have shown that these were present in traces or absent altogether (Ehlert, Hoeksma, and Velthof 2009).

Analyses performed in the framework of the SAFEMANURE study, showed that the 8 mineral concentrate samples complied with the proposed levels for Cu and Zn, while the limit for Hg (1 mg kg^{-1}) was exceeded by 70% of the mineral concentrate samples. It is still internally discussed if the analytical method used, was reliable and reproducible(Huygens et al. 2020).

The measured concentrations for Hg were similar to those in raw manure (mg Hg/kg dry matter). Thus, it could be assumed that mercury is preferentially distributed towards the liquid fraction during manure or digestate solid-liquid separation, although advanced solids removal and/or reverse osmosis processes may reduce Hg accumulation in mineral concentrates (Huygens et al. 2020)

Tests on struvite recovery from human urine showed that struvite without organic micro-pollutants and limited amount of metals could be recovered (Nuresys; Ceulemans and Schiettecatte 2013).

Garden owners

The presence of heavy metals and pathogens are obviously perceived by gardeners as negative attributes in a fertiliser of soil improver. Mostly not aware of the safety limits for heavy metals and pathogens, private consumers are known to apply several risk reducing strategies, like using price as a quality indicator and so buying the most expensive product, or relying on the brand name to signal a trustworthy supplier (Dahlin et al. 2017).

Labelling a product as "organic" communicates value to environmentally aware gardeners, which in many cases have the misconception that that 'organic' meant free from heavy metals, pesticide residues and chemicals (Dahlin et al. 2017).

Mineral fertiliser industry

Mineral fertiliser producers expect low levels of heavy metals in secondary raw materials. These specifically concern iron (Fe), metals that can volatize during the production process (Zn, Pb, Cd, Sn) and chloride, which can cause corrosion. Cu and chlorides can – similar to carbon- be catalysts for explosions in N-fertiliser production processes.

Unfortunately, when extracting phosphorus from secondary raw materials, obtaining a pure end product can be difficult, because often a mixture of P-salts (and often also a part organic material) are retrieved from digestate, manure or WWT sludge which first have to be acidulated or transformed into phosphoric acid which in turn can be further transformed. This process dissolves e.g. Mg from struvite, which will be transformed to Mg-sulphate in the process. This is an unwanted component which needs to be removed and therefore does not make struvite salts an interesting secondary P resource for chemical industry. Acidulation also dissolves the heavy metals present in the P-salts. A large amount of heavy metals therefore represents a high extraction cost (personal communication VCM, 2015).

Calcium phosphate ($Ca_3(PO_4)_2$) could potentially be of interest, but problems remain with granulation and there are issues with the extraction and production of clear crystals (Lebuf and Elsacker 2015). Calcium phosphate is highly preferred as raw material by the P fertilising industry. Therefore, it is important that it contains no iron, because iron phosphate is a not a soluble mineral phosphate and it could alter the colour of the gypsum by-product to brown. Absence (plasterboards) In the last case a of $CaCO_3$ is also required, since this would produce foam during the process.

Anyhow, some fertiliser companies are open to analyse a sample and feedback on how the concentration should be adjusted and which impurities should be resolved (personal communication VCM, 2018). Some fertiliser companies are even more flexible and claim to be able to use all kinds of phosphorus streams, preferably with high P content. This is because the impurities of the relatively small recovered phosphorus stream will be diluted during the process (Notenboom, Helmyr, and Van der Zandt 2017).

In the industrial practice, ammonium sulphate is a common by-product and will most likely have some impurities from different sources. The same counts for recovered ammonium sulphate from digestate.

For use in agriculture these impurities are regarded negligible, but to be able to create a value for this product in industry, and to for example crystallise it, a high concentration (>20%) and high purity is required (GEA 2010).

Table 3-2 gives an indication of quality requirements related to contaminants for recovered nutrient products set up by mineral fertiliser producers.

Table 3-2. Indicative criteria for contaminants provided by mineral fertiliser producers. DM=dry matter, TOC= total organic carbon, C = carbon, MgO=magnesium oxide, CaO=calcium oxide, SO_3=sulphur trioxide

	Recovered nutrient products [1]	**P products for Non-food uses [2]**	**P product For feed [3]**	**P product food and beverages [3]**	**Solid secondary raw material [4]**	**Liquid secondary raw material [4]**	**Ca-Phosphate [5]**
DM%					>85	-	
TOC%					<2	<2	
C%	Max 0,1% when 100% recovered products are used						<5
MgO%		<5ppm			>2	>1	
CaO %		<5ppm			>2	>1	
SO_3 %				<3400 SO4	>2	>1	
Fe %		<5ppm			>1	>1	
Mn %					>2	>1	
Zn (mg/kg)					<400	<400	Not present
Cu (mg/kg)					<100	<100	Not present
B (mg/kg)					>1000	>1000	
Mo (mg/kg)					>1000	>1000	
Cd (mg/kg)	Max 10%(w/w)			<3	<10	<10	Not present
As (mg/kg)			<40 ppm <8000ppm	<3	<40	<40	Not present
Pb (mg/kg)				<3	<150	<150	Not present
Al (mg/kg)					<1500	<1500	Not present
Cr (mg/kg)					<100	<100	Not present
Cr V (mg/kg)					0	0	Not present
Hg (mg/kg)				<3	<2	<2	Not present
Cl g/kg				<600			0,15
Volatile acids				<30			
SiO_2							As low as possible

Desirable valuable mandatory

1 (personal communication, 2014)

2 (Schipper, W., 2013. Personal communication)

3 (Dikov et al. 2014)

4 (Brañas and Moran 2016)

5 (Personal communication 2018)

3.2.2 Ease of use

Among respondents of the survey performed by (Power and Egan 2020), farmers ranked the ease of use as the 3rd most important parameter when selecting fertilisers.

Farmers not familiar with recycled nutrient fertilisers and advisors ranked it 2nd most important after price, particularly in Ireland.

In particular, farmers specified ease of use as: the ease of application/ spreading, followed by the fertiliser texture, ease of storage, fertiliser formulation, fertiliser size and dust formation.

Crop farmers and horticultural producers

Today, farmers depend on the availability of local agricultural contractors with equipment that can spread the products competitively. Respondents of a survey of European farmers mostly prefer farmers will prefer to use a dry, granulated or pelletised, concentrated fertiliser over liquid products, because of the ease of application and logistics (Jacobsen, Bonnichsen, and Tur-cardona 2017; Power and Egan 2020; Tur-Cardona et al. 2015). In contrast with the airiness of dried digestate, granulated products have bulk weights of over 600 kg per cubic meter, and interviewees indicated 300 kg per cubic meter as the minimum bulk weight needed to make long distance transportation cost effective (Dahlin et al. 2015). Eastern farmers also expressed preferences for semi-solid fertiliser products like digestate (Tur-cardona 2015).

In general, when it comes to liquid fertilisers, farmers prefer volumes comparable to their mineral fertiliser (Tur-cardona 2015). However, the recycled nutrient fertilisers are frequently liquids with low concentrations of nutrients, meaning that a much larger volume is needed for the same amount of nutrients administered with a mineral fertiliser.

The related transportation costs of these high volumes also often hinder distribution over long distances and practical application (Huttunen, Manninen, and Leskinen 2014). For example, on heavy soils (like clay) it is not advisable to spread large weights and liquid products because this might contribute to soil compaction, soil structure and crop damage. On lighter soils (sand, loam,…) liquid products have more opportunities (Smit, Prins, and Hoop 2000).

On the other hand, the current agricultural machinery also has limits on the practical application of small volumes (e.g. <10 tonnes/ha). To do this, the injector would have to drive faster, which could cause e.g. wheat to be teared loose (de Hoop et al. 2011). However, some recycled nutrient fertiliser producers have designed adapted application machinery for these types of products (personal communication Groot Zevert Vergisting, 2020). In general, administration with a sod injector, towing machine, arable injection or a tanker with trailing hoses are perceived by farmers as convenient for low-emission administration of liquid products (de Hoop et al. 2011).

Garden owners

Similar to farmers, hobby gardeners may perceive powdery products as dusty and product difficult to apply in a controlled way, particularly as it is susceptible to drifting with the wind. These customers want a homogenous product that can easily be applied with their current gardening tools and the products do not stand out aesthetically. Again, this translates to a preference for granulate products in this stakeholder group (Dahlin et al. 2015).

When it comes to potting soils, only more engaged gardeners pay attention to observable differences between potting soils. Fine grained and clump-free soils were preferred and associated with the better and more expensive products. The cheaper products were perceived as more likely to contain inert foreign materials such as plastics and stones (Dahlin et al. 2017).

Mineral fertiliser industry

When used as secondary raw material there are limitations set to the water content in function of treatability. For this reason, preferably dry, inorganic streams are used (Ceulemans and Schiettecatte 2013; Lebuf and Elsacker 2015). Additionally, some mineral fertiliser producers do not have the equipment to pelletise and can therefore not process sandy or slurry-like products.

Others are willing to accept slurries but prefer dried products because of the cost for logistics and drying. Organic fertiliser companies producing pellets can only handle solid products in their process lines.

The amount of struvite that can be added to organic fertilisers to improve the P content is limited, since struvite is not “sticky” enough to press in large quantities and the N/Mg/P ratio is not in line with products expected by the costumers. Others claim that they can pelletise struvite, but only when it contains more organic matter (personal communication, 2018).

There is an interest in N-containing liquid products, but mostly only a limited amount (10%) can be mixed with other products. Therefore, the N products would need to have a sufficiently high concentration to have an added value as secondary raw material (personal communication, 2018).

Fertiliser companies also require a constant supply of large volumes of secondary raw materials to keep the process line running. This is estimated at minimum 10% of annual volume of the primary resource they process. To adjust the production process to the impurities of the batch, minimum amounts of 20.000 tonnes can be demanded (personal communication, 2014).

Some mineral fertiliser producers are willing to accept smaller amounts, if they are compensated by a sensible gate fee and research results on lab scale towards the technical possibilities. This to provide a guarantee against damage and contamination of their production process.
Table 3-3 gives an indication of required volumes of related nutrient products set by mineral fertiliser producers.

Table 3-3. Indicative values preferred volumes and transport costs.

	Solid secondary raw material [1]	**Liquid secondary raw material [1]**	**Ca-phosphate [2]**	**Struvite [2]**
Tonnes/year	>5000	>5000	200 (P_2O_5) 1000 (80%DM)	1000
Transport costs	<15€/tonne	<15€/tonne		

1 (Brañas and Moran 2016)

2 Personal communication, 2018

3.2.3 Price

Crop farmers and horticultural producers

Most studies that asses user preferences confirm that for conventional arable farmers product cost was the most important quality for recycled nutrient fertilisers (Case et al. 2017; Jensen et al. 2016; Power and Egan 2020).

The results of the survey of Power and Egan, 2020 showed this result when users familiar with recycled nutrient fertilisers responded to an open-ended question. However, price ranked 2nd most important by them after product quality in a ranking exercise. In comparison, for non-users, the price per unit of N or other nutrients in particular in Ireland was the most important quality in recycled nutrient fertilisers (Power and Egan 2020).

Horticultural producers operate in markets with much higher profit margins and hence have a larger willingness to pay for the right product (Jensen et al. 2016).

As a producer of recycled nutrient fertilisers, when making a well-considered price estimation, one also has must consider the cost for application technique and maximum amount that can be applied each time within a growing season. (Gl Velthof 2011) suggest minimally 10% lower than the price of mineral fertilisers and application cost. (Jacobsen et al. 2017) concludes that it is difficult to get farmers to pay more than 50% of the mineral price for a bio-based product (Table 3-4).

Garden owners

In general, both for soils and fertilisers price is an important factor influencing the purchasing decision for fertilises (Dahlin et al. 2016). For some, low price is the decisive factor, and they only buy the cheapest product.

On the other hand, some consumers perceive price as a proxy for value and quality. Also, products labelled "organic" or "peat-free" and typically are among the more expensive soil amendment offerings (Dahlin et al. 2017).
In the potting soil market, where the profit margins are typically modest, this could be used to advantage (Dahlin et al. 2019).

Home garden products are mostly specialized fertilisers and can therefore be sold at much higher prices compared to fertilisers used in agriculture. However, this does not necessarily mean higher profit margins. These products incur additional manufacturing, packaging and marketing costs and, in addition, up to 60% of the remaining margin may be taken by the retailer (Dahlin et al. 2015; Dikov et al. 2014).

The consumer group of the serious hobby gardeners are prepared to pay a higher price for products of premium brands (e.g. that are perceived to be of premium quality) (Dahlin et al. 2017). When purchasing smaller quantities, the importance of the price per unit decreases. However, when larger quantities are required, the price per unit becomes increasingly more important.

For potting soil, since it is a product used in bulk quantities, customers sensitive to high prices place an even greater importance on price than they would for products like fertilisers that are purchased less frequently and in much smaller quantities (Dahlin et al. 2019).

Mineral fertiliser industry

Mineral fertiliser producers usually are only willing to pay a price for recovered nutrients that is lower than what they currently pay for their primary nutrient resource. They find this necessary to balance the investment costs needed to adjustments their production process to the secondary raw material of inferior quality (personal communication, 2018).
Table 3-5 gives an overview of indicative prices for recovered nutrient products. The price will be strongly influenced by the product quality and contaminants, transport cost, volumes, etc.

Reference	Product	Suggested price
(Notenboom et al. 2017)	Struvite from wastewater treatment in the Netherlands	65€/ton Excl. transport cost
(Ceulemans and Schiettecatte 2013)	Struvite from wastewater treatment in Belgium	50-90€/ton
(NuReSys, Waregem, BE, personal communication 2013)	Struvite from wastewater treatment in Belgium	45€/ton
(Bolzonella et al. 2017)	ammonium sulphate (6% N, 30% ammonium sulphate)	30 €/m3
(Dikov et al. 2014).	P-salt product that more or less meets with the quality requirements of the company	Same price as phosphate rock i.e. 176-327€/tonne P2O5)
(Bussink and van Dijk 2011a)	struvite	½ to 2/3 of price TSP
(VCM and Fraunhofer IGB 2015)	P-salt	50€/ton
Pilot Mineral concentrates NL 2009 2010	Mineral concentrates Price payed by farmers	 1,25€/ton 1,19€/ton
Personal communication SYSTEMIC plant, 2018	Ammonium sulphate solution	10-25€/ton

Table 3-4. Willingness-to-pay for recovered nutrient products based on literature and surveys.

Source	Product	Suggested price	Remark	Spreading cost
(Dodde 2012).	Mineral concentrate (7,12 kg N/ ton; 9,07 kg K2O/ ton)	2€/ton	Grass or corn	
(G. Velthof 2011)	N-rich products	Minimally 10% lower than price of CAN i.e. 210 €/ton		Application costs similar to those of mineral fertiliser application: estimated 2,5€ ton [2]
(Jacobsen et al. 2017)	Bio-based fertiliser	50% of price of mineral fertiliser	Class 2 farmers "old and not interested"	The cost of application of slurry is 1,34€/ ton and with 5 kg N per ton which is around 0,27€/ kg N. Application of mineral fertiliser is around 0,15€/kg N/ton.
	Bio-product 1: [4] Granulate, x7 volume of mineral fertiliser, 10% uncertainty in N content, with organic carbon	8% of price of mineral fertiliser Will not pay	Class 1 farmers "Young and interested" Class 2 farmers "old and not interested"	
	Bio-product 2: Granulate, x4 volume of mineral fertiliser, 5% uncertainty in N content, with organic carbon	34% of price of mineral fertiliser Will not pay	Class 1 farmers "Young and interested" Class 2 farmers "old and not interested"	
	Bio-product 3: Granulate, same volume as mineral fertiliser, no uncertainty in N content, with organic carbon and fast release of nutrients	51% of price of mineral fertiliser 27% of price of mineral fertiliser without fast release of nutrients 40% of price of mineral fertiliser with fast release of nutrients	Class 1 farmers "Young and interested" Class 2 farmers "old and not interested"	
(Power et al. 2019)	Recycling-derived fertiliser	Free of charge Same price of mineral fertiliser Same price or 80% of price of mineral fertiliser 50-80% of price of mineral fertiliser <50% of price of mineral fertiliser	18% 17% 19% 23% 14% Of 691 respondents	

| **Source** | **Product** | **Suggested price** | **Remark** | **Spreading cost** |

(Tur-Cardona et al. 2015)	Solid form	18% of price of mineral fertiliser	Flemish farmers (Belgium)
	Presence of organic carbon	28% of price of mineral fertiliser	
	Hygienisation	20% of price of mineral fertiliser	
	Fast release of nutrients	11% of price of mineral fertiliser	
(Tur-Cardona et al. 2018)	Solid fertiliser	44% of price of mineral fertiliser	Benelux
		39% of price of mineral fertiliser	Denmark
		31% of price of mineral fertiliser	Hungary and
	Organic carbon	52% of price of mineral fertiliser	Croatia
		17% of price of mineral fertiliser	Benelux
		35% of price of mineral fertiliser	Denmark
	Hygienic	42% of price of mineral fertiliser	France and
		30% of price of mineral fertiliser	Germany
		18% of price of mineral fertiliser	Benelux
	Fast nutrient release	22% of price of mineral fertiliser	Denmark
			France and Germany
			Benelux
	Pelletized	87% of N of mineral fertiliser price	
	All preferred characteristics	76% of N of mineral fertiliser price	
(Dahlin et al. 2015)	<u>Bulk marketing</u> : Raw (liquid) digestate	+5€/ton to -18€/ton	Switzerland, Germany,France, Austria, Netherlands
	Pellets	0 to 200€/ton	
	<u>Small scale marketing</u> : Powder product	9€/L	
	pellets	10€/ 4.5kg	
(VCM 2020)	Digestate (co-digestion)	-15€/ton	Flanders, Belgium
	Solid fraction digestate	-9€/ton	
	Liquid fraction digestate	-8€/ton	
	Dried digestate	-7€/ton	

Table 3-5. Indicative values mineral fertilising companies are willing to pay for recovered nutrient products.

Reference	Product	Suggested price
(Notenboom et al. 2017)	Struvite from wastewater treatment in the Netherlands	65€/ton Excl. transport cost
(Ceulemans and Schiettecatte 2013)	Struvite from wastewater treatment in Belgium	50-90€/ton
(NuReSys, Waregem, BE, personal communication 2013)	Struvite from wastewater treatment in Belgium	45€/ton
(Bolzonella et al. 2017)	ammonium sulphate (6% N, 30% ammonium sulphate)	30 €/m^3
(Dikov et al. 2014).	P-salt product that more or less meets with the quality requirements of the company	Same price as phosphate rock i.e. 176-327€/tonne P2O5)
(Bussink and van Dijk 2011a)	struvite	½ to 2/3 of price TSP
(VCM and Fraunhofer IGB 2015)	P-salt	50€/ton
Pilot Mineral concentrates NL 2009 2010	Mineral concentrates Price payed by farmers	 1,25€/ton 1,19€/ton
Personal communication SYSTEMIC plant, 2018	Ammonium sulphate solution	10-25€/ton

Conclusion

To get recovered products to enter the fertiliser market and compete on the same level as mineral fertilisers, they will first have to get acknowledged to be **applied as a mineral fertiliser**. The use of processed manure/digestate products under the same conditions as mineral fertilisers in nitrate vulnerable zones could be a major contributor for the feasibility of business cases of NRR in Europe. The creation of a market for the end-products of NRR techniques has a great impact on the financial viability of these investments.

On national level it is possible to ask for a derogation (See ANNEX II.5 as example). In the framework of a project, an individual exemption from the application limit can be obtained by the regional or national ministry, limited in time and space, product, user.

This is also possible to file a group exemption on a larger scale, but still limited in time. This is not per se in the framework of a project (see Pilots in the Netherlands).

A group of producers, each producing different products can contribute to a file to build their case for the European Commission. This should contain the description of the process, product characteristics, area on which the products would be applied, projects that could include and finance field trials.

A research centre should be involved to assure report on the field trials and independent organisation should be appointed to assess and monitor the product quality and monitor the number of products that is are applied. This is a time-consuming process for which biogas plants need the support of national sector organisations and research institutions.

The implementation of the RENURE criteria (from the SAFEMANURE study) in European and Member State legislation, would harmonize the individual derogations and pilot-status.

It can be concluded that many regulations on European level have in recent years been creating openings for the use and trade of these new recycled nutrient fertilisers (e.g. FPR, SAFEMANURE study) and the Green Deal Farm to Fork strategy and the Circular Economy Action plan will further enforce this. It can therefore be assumed that legislation is not hinder the use of recovered nutrient fertilisers but rather the market conditions.

Livestock and horticulture farmers are the stakeholder groups that would most likely prefer characteristics of recycled nutrient fertilisers. Especially, when they have not experienced deficiencies in fertilisation with manure or are already familiar with the use of these products (Tur-Cardona et al. 2018).

Yet, an increasing amount of farmers start to see the value of organic matter, especially in Netherlands, for their contribution to soil quality, which yields a certain soil amelioration value (Jensen et al. 2016; Power and Egan 2020). Compared to mineral fertilisers, the organic matter content is generally higher is digestate derived fertilisers (except in scrubber salt solutions and liquid concentrates).

Nonetheless, product quality (consistent nutrient content) and price are the main factors influencing the farmers decision. The results from the study of (Power and Egan 2020) add that ease of use is also an important characteristic.

The open-ended question on price indicated that farmers would be willing to use recycled nutrient fertilisers as alternative fertiliser if they would be subsidized, available free of charge or at a price that is sufficiently low to compete with traditional mineral fertilisers (Power and Egan 2020).
The lower cost would be necessary to compensate the higher logistics cost (transport and application), less predictable nutrient content and availability, physical parameters (compatibility with handling and spreading equipment) and potential nuisance (odour, dust) for neighbours (Jensen et al. 2016; Power and Egan 2020).

Price is even more important if farmers are not familiar yet with the recycled nutrient fertilisers (Power and Egan 2020). This mainly has to do with the fact that they have lower trust in these new, unknown fertilisers and don't see their intrinsic (nutrient) value (yet). (Tur-Cardona et al. 2018) states some reasons for this:

Firstly, farmers typically stick to their habits and for fertilisation they have been using mainly manure and chemical fertilisers, which they therefore consider as the most reliable source of nutrients. Consequently, they tend to be suspicious of any new and untried products. This is more pronounced in the stakeholder group of older farmers (+65 years), who would only use recycled nutrient fertilisers if they would be free of charge or subsidised (Power and Egan 2020).

Secondly, the variability of the characteristics, origins and nutrient concentrations of the recycled nutrient fertilisers complicates the marketing of standardised products.

Thirdly, because these products are unfamiliar, farmers don't yet trust nutrient uptake efficiency by different crops. Demonstration projects could help overcome this issue, however good yield results might also depend on proper application and experience with recycled nutrient fertilisers.

Lastly, most recycled nutrient fertilisers are processed in regions with nutrient surpluses. While local farmers could aware of the benefits of recycled nutrient fertilisers (e.g. their organic matter content and nutrient value), nutrient surplus areas have a lack of available local agricultural land to apply the recycled nutrient fertilisers (and their nutrients). This gives local farmers strong bargaining power regarding price. In contrast, farmers further away, which could use the nutrients in recycled nutrient fertilisers, might have a lower awareness of these products and therefore are more difficult to convince. Additionally, transportation costs might become important.

4 Market opportunities in agri- and horticulture

4.1 Tailor-made products

Crop farmers and horticultural producers

The composition of the different recycled nutrient fertilisers is determined by the technologies for NRR and their efficiency, but mainly also the composition of the digestate and thus the original waste streams and/or manure from which they are produced.

This makes that the composition of digestate or (dried) solid fraction of digestate rarely represents an optimal concentration and ratio between N-P-K and other nutrients in relation of the targeted crop requirements. Because of this, there will always be a 'limiting element' which determines how much you can supply as based on fertiliser regulations. This in turn will require the farmer to add the missing amounts of other nutrients to the specific crop demand or nutrient application limits. For this, farmers uses preferably highly concentrated, single nutrient mineral fertilisers, because of their ease of application, known composition and nutrient use efficiency.

If biobased fertilisers could be adaptable to serve variable crop requirements more directly at the source, being able to supply several nutrients at once in desired ratio, they would become more valuable to end-users who would otherwise need to blend and amend products to meet their specific crop requirements.

Most of the digestate derivatives are less suited for use in substrate cultivation, because it is crucial that the application of nutrients is aligned with the plant uptake and water quality. In a system with nutrient solutions and re-use of drainage water, there is a need for flexible fertilisers that dissolve quickly and contain only a small number of organic matter particles (ARBOR Project 2015; Dodde 2012).

Also, it should comply with the quality requirements for water uptake, amount of air, pH, EC and nutrients. Certain certification labels (e.g. RHP) guarantee these quality requirements are met, which will also limit the risks for the crops.

In the long run, it would certainly be possible to use mineral concentrates from animal manure if both producer and user are willing to adapt and compromise. Odour could however remain an issue.
The producer must refine the fertiliser to make it more suitable for greenhouse horticulture.
ANNEX II.3 explains a successful technology cascade that produces a nutrient solution for substrate cultivation.

Garden owners

There are several types of home garden products, granular multi-purpose organic fertilisers often containing dried poultry or cattle manure. Most garden fertilisers are commercially available as pellets or granules in boxes or bags of between 1-2 kg and they are odourless (Rigby and Smith 2011).
Therefore, thermally dried digestate products (blends), could fulfil the same role as currently available granular multi-purpose fertilisers (WRAP, 2011).

In practice, it would be ideal to mix the compost (55% DM) with a solid nitrogen rich product, avoiding the water content of the compost to be altered. Ammonium nitrate or ammonium sulphate solutions added during composting would largely volatize the ammonia again, which has to be cleaned out of the air, resulting in a zero operation. Crystallized ammonium sulphate could prove useful here but is not yet produced at AD plants.

Mineral concentrates or blends of recovered nutrient products could reach the required nutrient ratios of certain garden fertilisers (Table 4-1) if they could be concentrated and dried to eliminate odours.

Table 4-1. Average nutrient content of some gardening fertilisers (Rigby and Smith 2011).

		N	P	K
Multi-purpose garden fertilisers	Some of them are made from organic constituents	5,5	3,3 (1,5 soluble)	4,4
Slow-release and organic fertilisers	Slow release nutrient source for fruit and vegetables	5,5	3,1 (0,5 soluble)	7,5
Ericaceous plant foods	Organic-based and a slow release product	7,8	5,8 (3,5 soluble)	3,5
Root booster' fertilisers	From sterilised ground bone. slow release to encourage root development	3,8	7,8 (0,9 soluble)	0
Rose and shrub feeds	Some are organic	2,5	2,4	17,5
Liquid tomato feed		3,8	1,6 (1,6 soluble)	4,6

4.2 Soil substrates and potting soil

Peat is nowadays still the most abundant component of potting soil. The potting soil industry is however searching for sustainable alternatives. The alternative material must however meet stringent criteria of potting soil producers.

A potting soil ingredient should not contain bio-degradable organic matter. Seedlings are usually susceptible to salt, and consequently potting soil producers ask for products with a very low electric conductivity value, preferably below 1 µs cm^{-1}. Furthermore, the product should be odourless and free from pathogens. There are limits for heavy metals including Cu and Zn in growing media. Other contaminants of concern include residues of pesticides and herbicides which may be present in manure as well as in co-products. The presence of any phytotoxic compounds must be tested in a germination or phytotoxicity tests. Potting soil ingredients ideally have a slightly acidic pH.

Soil improvers with low nutrient contents may however become more valuable in the future because farmers are more and more aware of the importance of organic matter for maintaining soil quality. Soil improvers may thus be a profitable option for those products that cannot meet criteria for potting soil.

4.3 Fertilisers for organic farming

The European Green Deal is a roadmap to make the European economy sustainable. It includes targets for 2030 to reduce nutrient losses by at least 50%, while ensuring that there is no deterioration in soil fertility. This will reduce the use of fertilisers by at least 20% by 2030.
Additionally, the Commission will persue the objective of at least 25% of the EU's agricultural land under organic farming by 2030 (European Commission 2020).
Increasing organic farming practices will contribute to the reduction of artificial fertilisers use, because mineral nitrogen fertilisers are not allowed in organic farming (European Commission 2018).
On the other hand, the Commission will also work with Member States to extend recycling of organic waste into renewable fertilisers (European Commission 2020).

This poses the question if these recycled, renewable fertilisers would be applicable in organic farming.

Principles of organic farming

An important principle in organic farming is to maximally use natural resources which are internal to the system. This means that external inputs (feed, fertilisers, soil improvers, bio-stimulants, pesticides) and non-renewable resources are restricted. Plants should preferably be fed through the soil eco-system and not through soluble fertilisers added to the soil. Therefore, waste products and by-products of plant and animal origin from the farm can be re-used as nutrient inputs into cultivation (European Commission 2007).

Therefore, external fertilisers are allowed in organic farming, if no other appropriate management practices and methods exist.

In Europe, the import of external inputs such as fertilisers into organic farms is currently regulated by the Council Regulation (EC) No 2018/848 (European Commission 2018), which is interpreted and put into practice by the national governments (Table 4-2).

Table 4-2 Mentions of digestate on Annex I of Regulation (EC) No 889/2008.

	Name	Description, compositional requirements, conditions for use
A	Composted or fermented mixture of household waste	Product obtained from source separated household waste, which has been submitted to composting or to anaerobic fermentation for biogas production Only vegetable and animal household waste Only when produced in a closed and monitored collection system, accepted by the Member State
A	Composted or fermented mixture of vegetable matter	Product obtained from mixtures of vegetable matter, which have been submitted to composting or to anaerobic fermentation for biogas production
B	Biogas digestate containing animal by-products co-digested with material of plant or animal origin as listed in this Annex	Animal by-products (including by-products of wild animals) of category 3 and digestive tract content of category 2 (categories 2 and 3 as defined in Regulation (EC) No 1069/2009 of the European Parliament and of the Council (1)) must not be from factory farming origin. The Processes have to be in accordance with Commission Regulation (EU) No 142/2011. Not to be applied to edible parts of the crop

A: authorised under Regulation (EEC) No 2092/91 and carried over by Article 16(3)(c) of Regulation (EC) No 834/2007

B: authorised under Regulation (EC) No 834/2007

Each Member State can file a product for consideration, amendment or withdrawal from the list by providing a dossier to the European Commission containing argumentation and reasons for inclusion on the list.

Nutrient balance in organic farming

Like in conventional farming, the organic farming sector has been specializing and expanding, accompanied by increased production levels (Eurostat, ORG_CROPAR). However, when increasing the number of organic farms, the principles of organic farming of closing the loops for nutrients and resources, seem to hit the boundaries of production (Kirchmann, Ryan, and Bergström 2008). Several studies indicate that a lack of adequate nutrient supply is one of the major constraints of yields in organic farming (Askegaard et al. 2011; Berry et al. 2003; Lockeretz et al. 1980; Möller et al. 2006; Röös et al. 2018; Ryan, Derrick, and Dann 2004).

Nitrogen forms the foundation of proteins and is an important factor determining crop production and growth. Since mineral N fertilisers are not allowed, organic farming is depended on the mineralisation of N from organic matter and the breakdown of organic fertilisers. N deficiency is cited as the major yield limiting factor in organic farming, except from pastures with grazing cattle i.e. systems with also a large proportion of N_2 fixing forage crops (Clark et al. 1999; Kirchmann et al. 2007).

On the other hand, P and K balances of organic systems generally indicate a net loss of these nutrients through harvested products, (Fagerberg, Salomon, and Jonsson 1996; Kaffka and Koepf 1989; Reimer et al. 2020), unless sufficient volumes of approved organic manures are purchased (Ryan and Angus 2003).

Unfortunately, no comprehensive dataset is available on which kinds of inputs are actually used in organic farming in the Member States. However, for Flanders, Belgium (Reubens and Willekens 2012) describe that in 2009, there was not enough organic manure to supply for all nutrients needed in organic farming. Therefore, the Flemish organic farming sector was estimated to be depended for 30% on external, conventional animal manure. This underlies the demand of the organic sector for (external) nutrient input.

On the other hand, poultry manure is net exported out of the Flemish organic sector and send through acknowledged manure transporters or manure processors to organic arable land abroad: mainly France or Germany (Reubens and Willekens 2012). This has to do with a shortage of available organic land for this type of manure. This is due to the fact that organic poultry farming cannot make use of land related animal husbandry principles (i.e. chickens don’t drop their manure directly on the soil that needs to be fertilised). Also, stringent phosphorus limits make poultry manure unattractive for arable farmers because of its variability in composition and low N/P ratio.

This creates a paradox: certain types of organic manure don’t supply the nutrients in the right ratio’s, hence they are processed or exported. This stimulates the intensification of the sector and makes it rightly sensitive to social criticism. On the other hand, are the amounts of organic manure or digestate are not available in high enough quantity to meet the demand of the crops.

Despite the fact that approved external organic nutrient sources tend to have a lower nutrient utilisation efficiency than inorganic artificial fertilisers (Mattsson and Kjellquist 1992), there is an increasing trend in some countries to apply products such as meat meal, bone meal and wastes derived from the food industry (Kirchmann et al. 2008).

All these external, organic farming approved fertilisers involve an indirect nutrient transfer from conventional to organic farming and create a reliance on production systems fertilised with inorganic fertilisers (Berry et al. 2003; Kirchmann et al. 2008).

Recovered nutrients in organic farming?

Recovered P fertilisers

An ideal organic fertiliser has a high organic matter content, slowly available nutrients and high N/P ratio (Smit et al. 2000). Some of the recovered nutrient products, like struvite or renewable calcined phosphate, could be suited for this.

Struvite is a slow release P fertiliser and can be used to satisfy plant needs for phosphorus. A struvite dossier was filed back in 2011 by the UK and together with the calcined ashes dossier filed in 2014 by Austria (AshDec) evaluated by EGTOP (Expert Group for Technical advice in Organic Production). They formulated their official advice to DG AGRI in their 2016 report (EGTOP 2016) stating that struvite is in line with the organic fertiliser principeles. DG AGRI concluded that they would add these products to the list (Annex I of Regulation (EC) No 889/2008) when the Fertilising Product Regulation(EC) 2003/2003 was amended and implemented. This will happen when the STRUBIAS ANNEX is implemented in the Fertilising Products Regulation (2019/2009) and this enters into force in 26 June 2022.

Novel fertilisers obtained by stripping of ammonia

In general, organic farming prohibits the use of highly soluble mineral N fertilisers as it is clashing with the principle of feeding the soil life and not the plants.

However, a request for inclusion on the list was filed for scrubber salts of NH3-stripping-scrubbing, since N is often a limiting nutrient for crops. EGTOP concluded in their 2018 report that two principles conflict in this case:

1) The recycling of wastes and by-products of plant and animal origin is explicitly welcome (see Art 5(c) of Reg. 834/2007). Catching otherwise 'lost' minerals and recycling them is in line with the organic principles. Also, the catching of nitrogen can be an on-farm process.
2) On the other hand, there is a requirement that mineral fertilisers must be of low solubility (see Art. 4(b)(iii) of Reg. 834/2007). If such fertilisers were allowed, the Group is concerned that the current approach of organic crop nutrition which is primarily based on biological aspects of soil fertility would be replaced by a conventional, intensive approach focussing on nutrient supply. Additionally, the nutritional quality of crops can be decreased by high values of nitrate in the harvested crop. They stress that for cultivation of terrestrial crops, there are numerous alternatives in organic farming practices to achieve N supply. The products obtained are highly soluble and have a potential risk of nitrogen leaching, when applied in farming.

If such N fertiliser from scrubbing would be approved, it would also quickly add more administrative and technical questions:

How to define the minimum C/N ratio when these products are mixed with other organic products?
How can inspection verify that this minimum ratio is respected?
How long does the stripped nitrogen need to remain in the compost, to be transformed into low solubility organic forms?
And is this practically feasible?
Can the stripped nitrogen be sold to another organic farm?

As for the production of such N fertilisers, biological methods should be preferred to chemical methods, even if the use of certain chemicals can be acceptable, if no alternatives are available. If chemical air scrubbers with sulfuric acids are used, substantial amounts of sulphate are produced, which is not an authorized fertiliser.

Therefore, the EGTOP did not recommend including stripped nitrogen in Annex I, but welcomed research activities which lead to an acceptable mode of application of stripped nitrogen, in line with organic farming principles (EGTOP 2018).
In Denmark, the authorities did not consider it necessary to consult EGTOP and accepted the process of nitrogen stripping. They considered the processing as purely mechanical, and thus not altering the product it comes from, namely digestate. Several companies are now considering dossiers for acceptance of similar products (FiBl and SEGES, RELACS webinar, 2021).

N stripped digestate

Soil phosphate saturation in certain regions (Figure 2-3) will only be resolved in the long term. In the meantime, it will become increasingly difficult to use (digested) animal manure or co-digestate with high P content. Certain fertilisers with recovered nutrients(e.g. N stripped LF of digestate) could then ensure that fertilisation could be done with lower concentrations of phosphate. No dossier on such treated organic products has been filed yet.

One could also argue that by producing such a product, part of the carbon is also lost, since it is present in the solid fraction, together with the phosphate. The product therefore also contains highly soluble mineral nutrients, which is not desirable for improving the soil.

Technologies for nutrient recovery

Many technologies used to recover nutrients and organic matter from digestate use chemicals like acids or alkali (e.g. evaporation, NH_3-stripping-scrubbing, membrane filtration) or technological additives (e.g. flocculants, coagulants for enhanced separation). EGTOP concluded in their advice (EGTOP 2016) that the use of acids and alkali should be authorised only after case by case evaluation. Technological additives should in EGTOP's opinion not normally be present in organic fertilisers and should only be used when there is a clearly demonstrated need.

Discussion

Standpoint of organic farming organisations

At first sight, recycling of resources and nutrients as bio-based fertilisers is very much in line with the philosophy and foundation of organic farming, even more because the choice and supply of fertilisers for organic farming can be limited in some regions.

However, at the same time, the organic sector is greatly concerned about the integrity of their products, and therefore organic farmers, food processors and retailers may have some reservations against recycled products, due to concerns about contaminants, and consumer perceptions of the organic brand (Jensen et al. 2016).

The opinion of organic sectors in different member states varies on the degree in which also conventional manure should be banned from organic growing (e.g. Denmark vs. Norway). They all agree that they want to avoid that organic farming becomes a "dumping place" for excess nutrients from conventional farming. Digestate from source-separated organic waste, and struvite from sewage, are considered as interesting options for recycling of nutrients (personal communication, 2020).

The organic sector acknowledges that it cannot close the nutrient cycles 100% (cfr. nutrient deficits because of harvesting of agricultural production). One could argue if this is the case for nitrogen, but it is seen particularly in the use of micro-element fertilisers and potassium. Local recycling could provide access to nutrients that would otherwise be imported (Dionet Greece, 2021).

Organic farming organisations are also worried that opening the door for recovered nutrients would make them abandon the land-related principle of organic farming, which would risk setting up a separate circuit for organic fertilisers. This way organic fertilisation could be gradually reduced to a chemical issue: after all, does it make a qualitative difference whether an organic farmer uses digestate from organic inputs or from non-organic (contentious) inputs?(BioForum Vlaanderen 2019)

Additionally, if organic farming would increasingly rely on the use of such recycled rapid fertilisation forms, organic farmers who continue to effectively opt for ecological fertilisation methods with slow fertilisers could become competitively disadvantaged within the organic label (BioForum Vlaanderen 2019). The basic principles of organic farming start from the minimization of external inputs. Investing in the technological recycling of nutrients makes agriculture more dependent on inputs and technology, which necessitates further scaling up and specialization to keep everything financially feasible (BioForum Vlaanderen 2019).

The organic sector is generally of the opinion that nutrient recycling is an end-of-pipe technical solution that does not address the underlying problem and is not in accordance with the basic principles of organic farming (BioForum Vlaanderen 2019, Ecozept, 2021).

Is the organic farming sector ready for 2030?

Unless there are changes in regulations, the organic farmers will continue to rely on the import of nutrients from conventional production. If a large proportion of conventional farms is converted to organic farming (cfr. European Green Deal targets), the amounts of recyclable wastes produced would not be sufficient for high-yielding corps since they will be spread over a much larger area. It is also questionable if transfer of nutrients from natural systems would be enough to cover crops needs, resulting in decline in soil fertility (Kirchmann et al. 2008).

To sustain food production after complete adoption of organic farming, mixed animal-arable organic systems would require an increase of land area of 33%, while pure arable systems would require doubling

in area (Kirchmann et al. 2008). Only a 20% conversion to organic farming would be possible without increasing land use by more than 5%, without other food system changes.
The needed nitrogen supply could only be met if cropping intensities were increased and fallow land and intercropping were to be systematically used for legume production, which may not be possible because of e.g. water supply and feasibility of legume production in intercropping in some regions (Muller et al. 2017)

It seems a bit contradictory to imply an intensification to an agricultural sector which is not focussed on maximizing yield, but rather on being land-related resilient, and giving great attention to animal welfare and eco-system.

Organic farming alone as a dominant system will not provide a better long-term outcome in the search of sustainable forms of crop production than conventional alternatives. The real challenge will be intensifying this sector and including a synergy with the conventional agricultural sector. For this trade-offs and compromises will have to be made in both sectors to ultimately create a flexible approach where cropping systems are designed to meet specific environmental, economic and social goals unencumbered by dogmatic constraints (Kirchmann et al. 2008).

Although many arguments can be given to underline that recycled nutrient products are not in accordance with the basic principles of organic farming, they can have their place in future farming systems, which will have to optimally combine the best of both organic and conventional farming.
For example, an adequate farm- specific mixture of different external inputs, including recovered nutrient products, in combination with biological nitrogen fixation, which fits the nutrient requirements of the farm, might be a suitable solution.

Anyhow, further research on the safe application and regional availability of recycled fertilisers in the context of organic and conventional farming systems is necessary to find solutions for the future.

The H2020 project RELACS will create some interesting deliverables, working further on the above-mentioned themes:

- An overview on the current use of and needs for external nutrient inputs in five European regions with contrasting agroecological and socioeconomic conditions;
- A publication on the short-term and longer term benefits of recycled fertilisers with respect to soil quality
- European roadmap on contentious fertilisers (manure from conventional agriculture, recycled nutrients)
- An overview of and provide overall recommendation of recycling technologies suitable for organic agriculture

5 Setting up a market strategy

Before entailing in nutrient recovery from digestate, one has to figure out first which recovered nutrient products would have a demand in the region (Chapter 2). If there is no demand yet, the marketing strategy, including the communication and advertising has to be very convincing towards the target buyer group. Therefore, a good marketing strategy is the key to greater public acceptance and higher profit margins.

Since technology suppliers typically do not care for the marketing of the products produced by their systems (only exception is Ostara, see ANNEX II.4), the recycled nutrient producer will have to market his own products. The optimal marketing strategy will depend on the buyer group that is chosen, and which assets and specifications of the product are preferred by the buyer group (Table 5-1).

Table 5-1 Overview of target buyer groups, corresponding marketing level and preferred quantity and product composition.

Target buyer group	**Marketing level**	**Purchased quantity**	**Specific composition**
Farmers and horticulturalists[1]	Directly at the producer wholesaler	Large	++ Products that meet specific crop demand
Mineral fertiliser producers or chemical producing industries [1]	Directly at the producer	Large-medium	+++ Products with high purity
Traders in recycled products [1]	Directly at the producer	Large-medium	- Quality less important
Retailers, wholesalers, garden centres[2]	Directly at the producer	Large, but also variety of packages sizes	++ high variety of different products
Serious hobby gardeners [1]	specialized horticultural businesses or garden centres	Small	+++ products perceived to be of premium quality (i.e. premium brands)
Price sensitive or less engaged gardeners[3]	grocery stores, supermarkets, do-it-yourself stores or online direct at the producer	Small	+ General purpose fertilisers or soil improvers

1 Chapter 3.2

2 (Dahlin et al. 2015)

3 (Dahlin et al. 2016, 2017)

5.1 Communication, Promotion and Advertising Strategy

In general, a good promotion and advertising strategy will have a huge impact on the profit margin. For this, one needs to maximally respond to the preferences, social environment and even emotional triggers of the chosen target buyer group. Emotions and sentiment are the biggest driver of purchases: use a personal approach like giving away free samples to the local garden club, getting testimonials from farmers or known and respected people, creating a story behind the creation or producer of the product that people can relate to, etc.

It is beneficial to emphasize in communication and advertising the **pro-environmental effects** of the recovered nutrient products. The fact that a farmer will be reusing nutrients when buying the product, will boosts their environmental conscience, knowing they are not importing nutrients by means of mineral fertilisers (de Hoop et al. 2011).

Home gardeners are more emotionally triggered when it is mentioned that by using the products, they help to preserve endangered peatlands (Dewaelheyns et al. 2013; Dewaelheyns, Rogge, and Gulinck 2014).

Representatives of the NPK-industry are aware that primary elements (like P) are finite and that the demand for more sustainable fertilising products is growing due to a rising environmental awareness of the consumers.

For farmers it is important to mention that some recovered nutrient products contain **organic matter and valuable micro / trace elements**, in the absence of contaminants and pathogens and odour. Improvement of the soil structure by adding organic matter is the most important reason for farmers to use organic fertilisers (Case et al. 2017; Tur-Cardona et al. 2015).

For home gardeners, the advantage organic products offer as the ultimate slow-release fertilisers should be highlighted. Meaning that with the use of these fertilisers, it is very difficult for gardeners to over fertilize (and harm) their plants, which often happens in private gardens (Dewaelheyns et al. 2013, 2014).

Farmers and mineral fertiliser producers usually buy products in large quantities, so for this buyer groups, **packaging** is less relevant.

However, for retailers and home gardeners the package design is a vital element influencing their consumer behaviour because the product itself provides few visual cues to influence consumer purchases. A survey of consumer preferences concluded that women are the principal purchasers for fertilisers or soil improvers for the cultivation of flowers and vegetables. In this case, appealing packaging could illustrate the outcome gardeners expect after using the product: e.g. bright blooming flowers and large tasty-looking vegetables (Dahlin et al. 2017).

On the other hand, men frequently are instructed to buy the products in larger volumes that are heavy to carry (Dahlin et al. 2017). Packaging these products in bags provides producers a low-cost alternative to for example cardboard boxes and also has the advantage of allowing easy imprinting. Including handles, can make the bags more user-friendly and making them from recycled paper, adds to the packaged product's environmental appeal. Re-usable plastic buckets are another eco-and user-friendly alternative.

The **details about nutrient composition and information about product use**, need to appear on the packaging. This will help the end user to choose the right product. Many end users are unaware of the composition of soil amendments and fertilisers and this makes it difficult for them to assess the quality of a new product, making pre-sales services and advertising very important (Dahlin et al. 2015). Gardeners simply want a well-proven product that works and are not generally concerned to ask questions regarding the product's origin. Therefore, having a product package that simply states "from organic raw materials" works best (Dahlin et al. 2016, 2017). Nonetheless, some have a general resistance to biogas resulting from public discussions about the excessive cultivation of maize for fuel; second, consumers' concerns about product impurities such as inert foreign materials. Therefore, it is better not to mention that they are derived from biogas plants.

In general, it is best to not draw too much attention on the product's shortcomings compared to mineral fertilisers. If a certain product quality, form or performance cannot be obtained, it is better to highlight other aspects of your product or suggest solutions for the shortcomings in the advertising.

A **product name** is not necessary when targeting farmers and mineral fertiliser producers, yet in general it does differentiate from other products and creates a sign of recognition that lingers. A good product name for appealing to home gardeners relates to the properties or application of the product. They ultimately link the brand name to a certain quality and reputation, which needs to be built.

The specific terms used in product name, can really affect the consumers perception. (Dahlin et al. 2015) found that consumer preferences consistently favoured "renewable resources" and just as consistently rejected "biogas residues." Their results showed that "fermentation" is preferred over "biogas" in collocations with "residue".

A well-designed **website** provides the consumers a good overview of the available products and information on where and how to obtain them.

5.2 Direct contact with end users

By getting in **direct contact with the target buyer group** and entering their social environment, one can create a buyer experience that lasts longer and builds trust. Not only with consumers but also with local authorities and agricultural consultants, as these exercise a multiplying effect. For example, hosting open days with guided tour on the production plant, live demonstrations of field trials and application of your products, giving away free samples to the local garden club, ….These efforts can result in greater public acceptance of the products and can result in articles in local newspapers and agricultural journals which function as are free advertising. This **positive press** is an important multiplier.

Awareness of the benefits of digestate products remains relatively low, so education plays an important role in long-term marketing strategies. Reaching potential customers through presentations at regional agricultural and horticultural meetings as well as conventions and trade fairs serves this function (Dahlin et al. 2015).

If a third party is needed for the sale of the products, it is best to rely on qualified, **trustworthy personnel**. This way a recovered product producer can stay in control of the information that is given to the costumers, especially to farmers. Home gardeners also prefer distribution through a reputable or known retailer.

When dealing with farmers, higher chances of selling the recovered product can be achieved when one is able to **communicate correct information** about the legal status, application limitations, trade regulations of the recovered products. For both farmers and home gardeners, helping to **choose the right product** also builds trust in the product and the provider. This can include:

- which product best fills in the nutrient need, and if a certain amount of fertiliser can be eliminated because of this,
- finetune the specific fertilisation strategy to avoid over-fertilisation or deficiencies,
- calculate how much money can be saved by replacing mineral fertilisers and making more space for manure,
- calculate how much money can be saved in application cost (using a contractor or own equipment) and storage,
- which form of fertiliser best fits the user's soil structure.

These are complex calculation exercises for which most biogas plant owners don't have the experience nor the time. Research facilities or agricultural consultants can be approached for support.

Mineral fertiliser producers will have specific requirements for recovered nutrient products to be able to use it as a secondary raw material in their process (see Chapter 3.2). Convincing them of the value of the product will include technical discussions and price negotiation, which is best done by the recovered product producer themselves, without an intermediate party.

5.3 Extra actions that will boost the products' marketability

Most recovered nutrient products are relatively new, and many farmers are therefore unaware of their existence or have heard about them but don't see their value (yet) (Power et al. 2019). In their fertilisation methods, farmers are creatures of habit. Frequently, they will only use a new product if they can see it and witness the positive effects on their crop yield and quality.
Therefore, **showing the product's performance** compared to raw manure or mineral fertilisers might be able to persuade them. Universities and research facilities can be approached to set up scientifically reviewed field trials. Also, farmers can be approached who would like to use the product and demonstrate and testify on the results. If the outcome is good, this will aid to invalidate the prejudices about the recovered nutrient product. These results can then be used as informative advertising and will help buyers evaluate products that for the most part they do not fully understand.

The **environmental benefit (Life Cycle Analysis)** can be quantitatively determined and used to emphasize the sustainability and potential in circular economy of the products. This is the main advantage that recovered product have over mineral fertilisers. The consumer's attention for these aspects is growing, even in fertiliser producing companies. Again universities, research facilities, coordination platforms and agricultural consultants can be approached for information and support.

Investigating if a cheap, effective, easy in use and low-emission **application technology** can be coupled to certain products can create an extra added value for consumers. If possible, the recovered product producer can provide the application service and equipment himself, hereby gaining extra profit and costumer reliance. If not, a good relation and agreement with a contractor can be established to do this.

Also, **other related services and products** can be provided, like storage, training on application, green electricity, process water, irrigation water, pure water or heat and CO_2 to greenhouse growers. Providing other things next to the product helps to build a sustainable, trustworthy relationship with clients and creates a total package experience.

Many farmers have experienced deficiencies or nutrient surplus by using manure or mineral fertiliser. Creating **products with a tailor-made composition** provides an answer to this issue and differentiate the products in the market and add to their competitiveness. By blending different recovered nutrient products, the required nutrient concentrations and ratios could be achieved. This way, different specialized fertilisers are created, which are appealing form farmers but especially for gardeners and retailers (Table 5-1).

When attempting to sell the recovered nutrient products to a mineral fertiliser producer, it would be beneficial for both parties if a collaboration is designed that **integrates the logistics of products** from and to the location of the mineral fertiliser producer. Find a way to streamline storage and supply of chemicals to the biogas plant and recovered nutrient products to the fertiliser producer in a cost-efficient way. Also, if large volumes of the product are required, this can be achieved by establishing joint ventures with other biogas plants. This is a complex cost-benefit analysis for which most biogas plant owners don't have the experience nor the time and therefore will need to approach universities, research facilities, coordination platforms, agricultural consultants. A good example can be read in ANNEX II.1.

Niche markets (see ANNEX I) mostly require products with very specific characterisation and are frequently still in development. Entering these markets usually takes a lot of research, testing, finetuning of product, logistics, negotiating, etc. but can eventually render much higher profit margins and encounters less competition. This is a time-, money- and energy consuming process for which most biogas plants don't have the resources nor are experienced for. Entering these niche markets will need the support of universities, research facilities, consultants, private corporations, funding etc.

An alternative, to alleviate biogas plants from the money- and energy consuming marketing process, is to create an independent (non-profit) organisation, company, project or joint venture on national level or EU level that:

- Includes or has good relationship with people from the complete chain of stakeholders:
  - feedstock suppliers (animal farmers, food industry, etc.),
  - provinces (for permits and allocation of plants),
  - governmental institutes, agricultural consultants, agricultural organizations, universities, labs (for independent, reliable information on performance, safety, composition and legislation of the products)
  - retailers, mineral fertiliser producers, industry,
  - biogas plants producing recovered nutrient products.
- Helps to choose the right recovered nutrient product for the demand of each end user.
- Does public relations for the different products of the biogas plants.
- Gets technology providers to develop user friendly (and preferable cheap) equipment for farmers to apply these new fertilisers.
- Buys, rents and leases user friendly application equipment best fitted for each recovered product.
- Motivates technology companies to engage in product sales and marketing – the Ostara business model is a good example, but it needs quite a high initial investment which seems to be difficult to cover.
- Functions as independent trading platform for feedstocks and contractor services.
- Negotiates with mineral fertiliser companies, industries and retailers.
- Establishes sustainable logistic chains to end users.
- Makes an evaluation of the regional NRR pilots with regard to the economic feasibility and environmental aspects and informs biogas plants on the developments.
- And above all, is trusted by Biogas plant owners it works for.

Conclusions

Geography appears to be a key driver of pricing for recovered nutrient products since transportation costs, especially those associated with liquid products, increase substantially as distance increases. Therefore, **sound logistics planning and management** are vital for the profitability of NRR.

Also, one needs to be aware that creating one very marketable product, could produce a few other less marketable (by-)products, that could shift the business case to negative. Therefore, **all products need to be taken into consideration** when developing a market strategy and a sustainable, profitable balance needs to be created, selling or disposing all the produced products.

When eventually a biogas plant achieves to create a positive market value for all the produced end products, this will not automatically make a positive business case.
The **total picture** of getting feedstock, implantation and running of the digestate treatment technologies, the disposal of all side streams or by-products, in combination with the production of biogas, needs to be in balance to get to a profitable business case.

Nonetheless, the disposal or marketing of digestate products is a Key Performance Indicator in the business case of a biogas plant (see SYSTEMIC D.2.4 Final report on the development and application of economic key performance indicators (KPIs)).

In general, **biogas plants currently tend to underestimate the impact of a good marketing strategy** and should make greater efforts to better understand and respond to consumer preferences and concerns and develop effective and long-term marketing strategies for recovered nutrient products.

Direct contact with the end user and making your product relatable are key when influencing consumer perception and willingness to buy the product.

Yet, many of the suggested actions in the market strategies (Chapter 4) will often exceed the staff capacity, experience, available time and budget of biogas plants, which are mostly SME's already preoccupied with their core business: producing biogas.
However, if the recovered products qualify as a good alternative fertiliser or secondary raw material, mineral fertiliser producers are sure that they could create a market for this in a short time notice. In this case the biogas plant will not need to invest in advertising, promotion and communication themselves.
The lack of marketing power of (smaller) biogas plants could be eliminated by establishing a regional cooperation of biogas plants, contractors and/or agricultural advisors. 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 et al. 2015).

6 Outreach Locations

This chapter provides the prospects of marketing products from digestate for each Outreach Location region. The end products produced, and technologies installed at the Outreach Locations can be found in Table 1-1. All Demo Plants and Outrach Locations are located in regions with (local) nutrient surplus (Figure 2-1, Figure 2-3 and Figure 6-1)

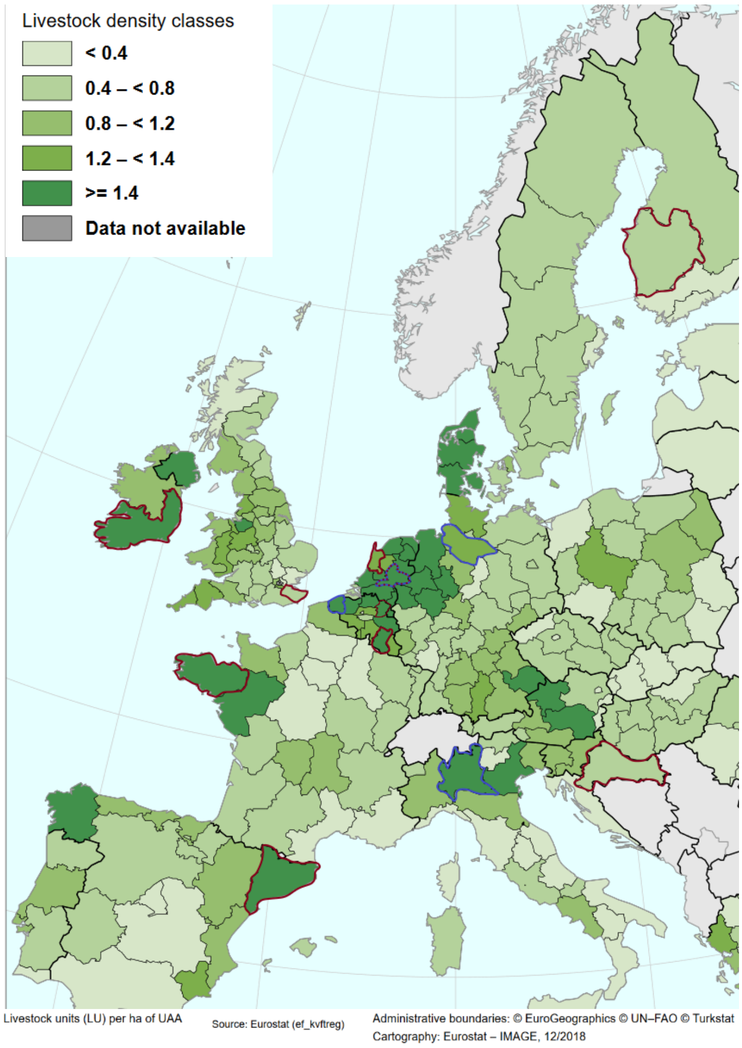


Figure 6-1 Livestock density in NUTS 2 regions in Europe 2018. Source: Eurostat. Demo Plants indicated in purple: West-Flanders (BE), Lombardia (IT), Gelderland (NL), Lüneburg (DE). Outreach Locations indicated in red: Limburg (BE), Luxembourg (BE), Noord-Holland (NL), Gelderland (NL), Länsi-Suomi (FI), Catalonia (ES), Bretange (FR), Southern Ireland (IR), Kent (UK), Kontinentia Hrvatska (HR)

6.1 Biogas Bree, Flanders, Belgium

Biogas Bree is located in a region with a surplus amount of manure due to intensive livestock farming (Figure 6-1) and experience a growing competition for application of digestate with manure and digestate form other neighbouring anaerobic digestion plants. Phosphorus is typically the first limiting factor when fertilising in Flanders with manure products followed by limitation due to the N content of manure products (Figure 2-1 and Figure 2-3). In addition, manure (derived products) are not allowed to be used in Wallonia. Consequently, digestate has a negative price when used as fertiliser in the region of the plants.

In the Flanders, all crops discussed in Chapter 2 contribute to a relatively high share of the utilised agricultural area. For the regions near Biogas Bree (±100km), cereals, maize and grassland cover a substantial amount of the agricultural land (Table 6-1). For these crops, ammonium sulphate, NK concentrates or liquid fraction from digestate could be interesting alternative fertilisers (Chapter 2). Plant owners can also focus on other markets, which are described below.

Table 6-1 Crops percentage (%) of UAA(utilised agricultural area: cropland + grassland) in the region of Biogas Bree and Waterleau New Energy(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	
Potatoes	4,3		1,7		6,5	
Sugar beet	2,5		3,5		2,9	

1. RENURE products

Criteria are now being developed to allow the use of RENURE (REcovered Nitrogen from manuRE) 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) (see 3.1.5 SAFEMANURE). In Flanders, ammonium sulphate produced by acid air scrubbing can be applied above the application limit of 170 kg N /ha^{-1} /$year^{-1}$. Nevertheless, marketing of such RENURE products is still challenging 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 synthetic N fertilisers. Also, the acid pH of ammonium sulphate makes farmers more reluctant to use this product. Biogas Bree has therefore improved their acid air washing system in a way that it can produce ammonium sulphate with neutral pH. They are also investing in improving the image of ammonium sulphate as alternative for mineral N fertilisers with the UNIR project ("Flanders Circular grant"). The potential of crystallizing ammonium sulphate and selling it to industry, could be looked into, though this is technically still a challenge.

2. Tailor made fertilisers for export

Biogas Bree produces dried solid fraction of the digestate. These products typically have a high P:N ratio that does not meet crop demand. Producing granular fertiliser with custom-specific N:P:K ratio will give them an advantage in the market for dried organic fertiliser.
fertiliser. Biogas Bree already decided to invest advanced dryers which enables them to blend solid fraction of digestate, with dried digested pig manure and N-rich liquid fraction or ammonium sulphate into a tailor-made fertiliser. Such a tailor -made granular product can be sold to retailers or individuals as garden fertiliser against high prices but are also suitable for export.
Since phosphorus limits are always the first ones met when fertilising in Flanders with manure products, creating a P poor solid fraction and P fertiliser, following the example of Groot Zevert Vergisting in The Netherlands, could also be an option. However, Biogas Bree has already invested in advanced dryers and have sufficient amount of thermal heat available implying that an investment in a P stripper may not be economically justifiable.

6.2 Ferme du Faascht-SCRL Kessler, Wallonia, Belgium

Kessler is located in the south of Wallonia which has a high livestock density. The region is however not designated as a nitrate vulnerable zone (Figure 6-2) and Kessler is therefore still able to dispose most of its liquid N-rich fraction on his own fields or on their partners farms in a radius of 10 km. The Kessler biogas plant mostly treats cattle manure from their own farm. Phosphorus is a however a limiting factor when applying manure derived products (Figure 2-3).
80% of the digestate is spread on grassland, the rest is used for %) . And the other part is for corn culture, the most dominant crop cultivated in the region (Table 6-2). Scrubber salts, liquid fraction of digestate, NK concentrate, and solid fraction could be useful fertilising products for these crops, able to fill the nutrient gap from basis fertilisation with manure.

Kessler has already found a niche market for part of their dried solid fraction of digestate. Tests have been running where this product is used as fertiliser in greenhouses for cultivation of tomatoes. In 2021, the building of their own greenhouse for tomato cultivation will be executed. The remaining part of the solid P rich digestate is used on their own land.
Kessler is already searching for alternatives in case their region in Wallonia is to become a nitrate vulnerable zone in the future. They focus therefore first on acquiring the autorization to spread the digestate in the GD of Luxembourg and then on technologies to reduce the N content by e.g. biological treatment, but investment in production of NK concentrates complying with RENURE criteria would be a more sustainable option. Production of NK concentrates is likely also economically feasible considering the fact that Kessler has sufficient storage capacity on-site and would be able to apply NK concentrate on his land or in Luxembourg if a derogation is approved.

Figure 6-2 Nitrate Vulnerable Zones in Wallonia. Source :www.rochefort.be

Table 6-2 Crops percentage (%) of UAA(utilised agricultural area: cropland + grassland) in the region of SCRL Kessler (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		

6.3 Waternet, Noord-Holland, and GMB, Gelderland, The Netherlands

Both Waternet and GMB produce digestate from sewage sludge. Currently, both plants have to incinerate the solid fraction of sewage sludge digestate because it can contain -besides a lot of nutrients and organic matter- also heavy metals, pharmaceuticals, hormonally active substances, persistent organic pollutants, etc. Dutch and European (waste) legislation and risk perception of customers and consumers prevents direct use of this end-product.

The digestate from GMB originates from source-separated treatment of non-polluted streams such as food-waste but is mixed with sewage sludge before separation in a centrifuge.
In 2018, GMB got their dried, composted sewage sludge digestate recognized in France as a P fertiliser under the name "Tradiphos". The product is considered as a homogeneous and odourless soil improver, which is particularly suitable for corn, grain and beets. In 2019, they were able to sell over 4,200 tons of Tradiphos in Northern France, which translates to 186,000 kilos of phosphate (P_2O_5). As an alternative for mineral fertilisers, Tradiphos could prevent the use of more than 1,000 tons of Superphosphate. GMB intends to further expand Tradiphos' sales to France, however the Substances of Very High Concern can pose a risk to their sales plan.

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 Fertilising Products Regulation (EU/2019/1009) (Huygens et al. 2019).

In Gelderland the most dominantly cultivated crops were in 2019: maize (56% of cultivated area (CA)), potatoes (10% of CA) and winter wheat (8% of CA), sugar beets (4%) (Figure 2-4, Figure 2-5, Figure 2-7). GMB is already using the produced ammonium sulphate as a fertiliser in agriculture. It is sold to fertiliser traders who are selling it to farmers in the region of Gelderland and probably in the northern provinces of Groningen, Drenthe and Overijssel.

At Waternet struvite is recovered from the digestate and is sold to ICL Fertilisers as secondary raw material for phosphorus fertilisers. Currently only 20% of the total phosphorus present in the digestate can be recovered as struvite. Waternet has the ambition to increase the amount of recovered phosphorus substantially.

6.4 Greencreate W2V/RIKA Biofuels, Kent, United Kingdom

RIKA Biofuels / Green Create W2V, is building a mesophilic anaerobic digester (AD) at Fridays' Knoxbridge Farm, Frittenden, Cranbrook, Kent, United Kingdom. The plant shall digest 55,000 tonnes per annum of poultry manure and 2,500 tonnes of straw from the Friday's chicken farm. As part of the plant's design nutrient recovery and recycling (NRR) technologies will be employed producing valuable by-products from the installation such as concentrated digestate as organic fertilising product and a mineral ammonium sulphate solution.

The concentrated N-P-K digestate will be sold via local solid fertilizer contractor(s) at an estimated sales price of GBP 5/tonne. 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.

In the future higher value markets should be realised by further processing and/or packaging of the by-products or by addressing selected niche markets.
RIKA intends to reserve 20% of the total volumes (300 tonnes) to promote recycled product to retail buyers. A good example for a recycling product from DVO digesting plants is Magic Dirt™(ANNEX II.2Magic dirt®.

6.5 Bojana, Croatia

Bojana is located in a region with intensive livestock farming. They treat cattle manure and agro-industrial waste. The digestate of Bojana biogas plant is separated and the solid fraction is mixed with straw and reused as bedding material for the cows. This is an important synergy for the surrounding farms to avoid the cost of straw. The liquid fraction is spread on the land as alternative for mineral fertiliser. The transport is maximum 50 km on the road, 25 km in a circle around the farm. Therefore, Bojana has already a circular business case.
Bojana is not located in a nitrate vulnerable zone and has therefore no problem to dispose of their digestate as such in the area. However, Bojana is looking into opportunities to increase the value of their digestate and make use of the residual heat.

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 CAN (27 %). When choosing fertilisers, Croatian farmers pay a lot of attention to the price of product, but also don´t ignore the content of the fertiliser (amount of nutrients).
Ideally, the air from the lagoon should be cleaned with an acid air scrubber or the digestate itself could be stripped and scrubbed from ammonia, recovering the nitrogen as ammonium sulphate or nitrate and creating an odour free digestate. Ammonium sulphate is a good fertiliser for filling in the nitrogen demand of grass, maize and cereals, the main cultivated crops in the region (Table 6-3).
However, Bojana has currently no interest in production of ammonium sulphate or ammonium nitrate or ammonia water because of the high investments needed to produce such products. Yet, these products could prove also useful to blend with solid fraction and create a dried product. Bojana, already has residual heat available for drying. Solid, tailor-made products approach better the crops needs, can cut transport costs due to lower volumes and are easy to apply by a farmer. Such products could therefore have a positive marketing value.
Alternatively, also production of NK concentrates could be an option though an economic assessment is needed to quantify the benefits of such an investment.

Table 6-3 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
Sugar beet	0,5

6.6 Emeraude Bioénergie-Cooperl, France

The region is characterised with intensive pig husbandry, creating a manure surplus. The biogas plant Emeraude Bioenergie already has developed a circular system accepting this manure, together with slaughterhouse waste from the neighbouring slaughterhouse. Fertival, part of the Cooperl group and located next to the biogas plant, dries the digestate and sells it as organic fertiliser.
Yet, Emeraude still has an unvalorised end-product, namely the ammonium sulphate. This could be commercialized to farmers as alternative to mineral N fertiliser or used to make specialized blends.

6.7 Greengas AD, Ireland

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. Ireland's agricultural land is mainly grassland, and some cereal cultivation (Table 6-4). For grassland, having high N, K and sulphur needs, ammonium sulphate is the ideal fertiliser (Chapter 2). The region of Greengas AD is located in an area with possible sulphur deficiency (Figure 6-3). On S deficient soils, it is advised to apply 20 kg/ha per year for grazed swards and for silage swards on S deficient soils, apply 20 kg/ha of S per cut (Teagasc et al. 2016).

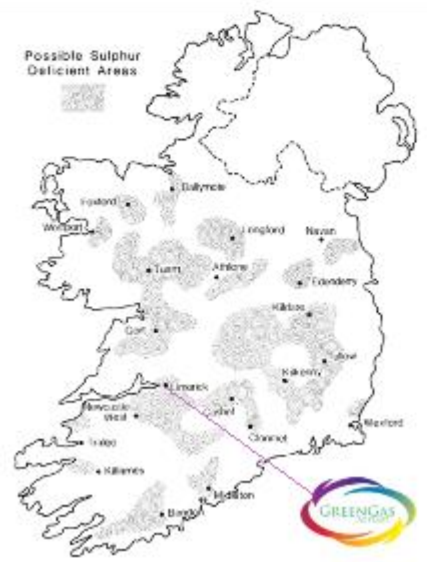


Figure 6-3 Areas in Ireland that are possibly deficient in Sulphur (Teagasc et al. 2016)

The 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. However, they prefer low volumes with a high concentration of nutrients.

Greengas AD is therefore interested in ways to reduce the moisture content of the digestate. (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.

Table 6-4 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

6.8 Makassar- Somenergia, Catalonia, Spain

Digestate has no (negative or positive) value in Spain and the land to spread the digestate on in the area is limited. Since there are no subsidies for biogas in Spain, the biogas plant cannot make large investments in expensive nutrient recovery technologies.
Separation of the digestate by means of a centrifuge is a simple 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.

6.9 Atria, Finland

Atria Biogas and NRR Plant project is located in Seinäjoki, a region characterized by intensive primary production and has a higher P soil status (region of 100km radius) than the rest of the country (*Figure 2-3*). The general P limit in Finland is 32 kg P/ha and Finland is a Nitrogen Vulnerable Zone.
In Finland, growing season is quite short. There are only <2 months per year when the digestate spreading makes sense, since spreading into frozen land is not allowed nor useful. The rest of the year, the produced digestate has to be stored, which requires a very large storing capacity.
The biogas plant will be located close to Atria's slaughterhouses, and is designed to make optimal use of energy and manure (as a resource) to not be hindered by the legal constraints.

One of key aspects of the Atria business case it the production of LBG, a "green" fuel that will partly be used for the trucks delivering the manure and disposing the nutrient products. The largest part of the LBG will be purchased by other customers. Atria will produce an amount of LBG which is comparable to 10 million litres of diesel.

Atria estimates to process 250.000 ton digestate per year into 43,000 ton solid fraction digestate, and 30,500 ton NPK concentrate. The evaporator is assumed to be under maintenance three weeks per year. During that time, 11,000 tons of liquid fraction of digestate is produced.
The reverse osmosis unit and activated carbon purify the evaporator condensate to less than 100,000 ton dischargeable water per year. Approximately 40,000-60,000 tons of evaporator condensate is not purified for discharge and is instead is recycled in the process for dilution needs, cleaning and polymer solution. By producing this clean water, <50% of the initial digestate volume needs to be stored and transported as diluted digestate or treated as wastewater.

Part of the NPK-concentrate can be mixed with the solid fraction to improve the fertiliser properties of solid fraction. Both products will be transported economically into areas where nutrients are really needed. The plant will be located in agricultural area and the main crops are cereals as well as broad bean, pea and rapeseed/rape. Part of the digestate products can be used for potatoes as well. Maize and beets are not grown in the region, but can in the future. It is estimated that recoverd nutrient products can potentially fill in the demand of arable farms within a 40 km radius(Figure 6-4).

The 43,000 tons of solid fraction per year relate to 418 tons of P/year and due to these large volumes it could be economically feasible to recover this as phosphorus salts with the a P stripping system with acidification. For struvite precipitation, the concentration of phosphorus is relatively low (1,9 kg P/ton) and most phosphorus will be organically bound and therefore not available for precipitation. The remaining solid fraction, low in P, could be a valuable soil improver.

Figure 6-4 Location of arable farms with nutrient demand in the region of Atria's biogas plants. Green dot = location biogas plant Atria, red dots = potential nutrient users. Red circle= 40 km radius

Conclusions

This market study report is meant to inspire biogas plants and inform them about the market opportunities of different types of recovered nutrient products from digestate with current technologies. It will be included in the “Business Development Package” **to support decision making for implementation of the innovative business cases in Europe.**
In 2021, the Outreach Locations the content of the BDP will be applied on the Outreach Locations and these outcomes will be used to take the first steps in exploring possibilities to better market their current products or produce more commercially interesting or demand driven products. Eventually **of region-specific business cases and scenarios with NRR will be set up for the Outreach Locations.**
This report and the BDP facilitate the transfer of knowledge and ongoing experiences from the demonstration plants and outreach locations to other biogas plant and identify opportunities for the uptake of the newly developed techniques into the business cases.

References

Abts, Mathias, Alfons Anthonissen, Laurence Hubrecht, Geert Rombouts, Ivan Ryckaert, Alex De Vliegher, Joos Latré, Gert Van De Ven, and Wendy Odeurs. 2016. *Praktijkgids Bemesting*.

Ackermann, F. and C. Eden. 2011. "Strategic Management of Stakeholders: Theory and Practice. Long Range Planning." *Arla, "Arlagården Quality Assurance Programme" Version 5.2, with Effect in Denmark from January 2017* 44(3):179–96.

Afif, Ahmed, Nikdalila Radenahmad, Quentin Cheok, Shahriar Shams, Jung H. Kim, and Abul K. Azad. 2016. "Ammonia-Fed Fuel Cells: A Comprehensive Review."

Agreon. 2013. "Quick-Win Projecten: Aanpassing van Een Preibewerkingsmachine Voor Spuiwatertoepassing." Retrieved (http://www.agreon.be/nl/quick-wins/overzicht/q/14/Aanpassing van een preibewerkingsmachine voor spuiwatertoepassing/).

Anon. n.d. "Emis: Energie- En Milieu-Informatiesysteem Voor Het Vlaamse Gewest." Retrieved (https://emis.vito.be/).

ARBOR Project. 2015. *Update of the ARBOR Benchmark Report: Biomass for Energy in the North West European Region: Statistics, Targets and Regional Case Studies.*

Askegaard, M., J. E. Olesen, I. A. Rasmussen, and K. Kristensen. 2011. "Nitrate Leaching from Organic Arable Crop Rotations Is Mostly Determined by Autumn Field Management." *Agriculture, Ecosystems and Environment*.

Berry, P. M., E. A. Stockdale, R. Sylvester-Bradley, L. Philipps, K. A. Smith, E. I. Lord, C. A. Watson, and S. Fortune. 2003. "N, P and K Budgets for Crop Rotations on Nine Organic Farms in the UK." *Soil Use and Management*.

BioForum Vlaanderen. 2019. "Recyclage van Nutriënten in Bio : Wenselijk of Niet ?"

Bolzonella, D., F. Fatone, M. Gottardo, and N. Frison. 2017. "Nutrients Recovery from Anaerobic Digestate of Agro-Waste: Techno-Economic Assessment of Full Scale Applications."

Brañas, Javier and Antonio Moran. 2016. "NewFert. Nutrient Recovery from Biobased Waste for Fertiliser Production."

Brown, Trevor. 2017. "Bunker Ammonia: New Report Quantifies Ammonia as 'the Most Competitive' Fuel for Zero-Emission Maritime Vessels in 2030 – Ammonia Energy." *Ammonia Energy*, December.

Bussink, Wim and Tonnis van Dijk. 2011a. *Fact Sheet: Mogelijkheden En Waarde van Alternatieve Meststoffen in de Akkerbouw*.

Bussink, Wim and Tonnis van Dijk. 2011b. *Fact Sheet: Mogelijkheden En Waarde van Alternatieve Meststoffen in de Akkerbouw - Bijlage 1. Een Overzicht van Vloeibare Meststoffen Die Beschikbaar Zijn Voor de Akkerbouw.*

Case, S. D. C., M. Oelofse, Y. Hou, O. Oenema, and L. S. Jensen. 2017. "Farmer Perceptions and Use of Organic Waste Products as Fertilisers – A Survey Study of Potential Benefits and Barriers." *Agricultural Systems* 151:84–95.

Ceulemans, Johan and Wim Schiettecatte. 2013. *WP2 Inventarisatie van Bestaande Technieken Voor Nutriënt Recuperatie Uit Digestaat En Mest*.

Chironna, Robert and Boris Altshuler. 2001. "The Chemical Aspect of NOx Scrubbing." *CR Clean Air Group, LCC*, 6.

Clark, M. Sean, William R. Horwath, Carol Shennan, Kate M. Scow, W. Thomas Lantni, and Howard Ferris. 1999. "Nitrogen, Weeds and Water as Yield-Limiting Factors in Conventional, Low-Input, and Organic Tomato Systems." *Agriculture, Ecosystems and Environment*.

Colenbrander, Erik. 2018. "Fosfaat Meststof Toegestaan Met Behoud van Derogatie | Melkvee.Nl - Nieuws En Kennis Voor de Melkveehouder." *Melkvee*. Retrieved November 18, 2019 (https://www.melkvee.nl/artikel/69706-fosfaat-meststof-toegestaan-met-behoud-van-derogatie/).

Dahlin, Johannes, Christoph Beuthner, Verena Halbherr, Peter Kurz, Michael Nelles, and Carsten Herbes. 2019. "Sustainable Compost and Potting Soil Marketing: Private Gardener Preferences." *Journal of Cleaner*

Production 208:1603–12.

Dahlin, Johannes, Verena Halbherr, Peter Kurz, Michael Nelles, Carsten Herbes, and Richard Henry Moore. 2016. "Marketing Green Fertilizers: Insights into Consumer Preferences."

Dahlin, Johannes, Carsten Herbes, and Michael Nelles. 2015. "Biogas Digestate Marketing: Qualitative Insights into the Supply Side." *"Resources, Conservation & Recycling"* 104:152–61.

Dahlin, Johannes, Michael Nelles, and Carsten Herbes. 2017. "Biogas Digestate Management: Evaluating the Attitudes and Perceptions of German Gardeners towards Digestate-Based Soil Amendments." *Resources, Conservation and Recycling* 118:27–38.

David, William I. F., Joshua W. Makepeace, Samantha K. Callear, Hazel M. A. Hunter, James D. Taylor, Thomas J. Wood, and Martin O. Jones. 2014. "Hydrogen Production from Ammonia Using Sodium Amide." *Journal of the American Chemical Society* 136(38).

Decaluwe, Geron. 2016. "Ammoniumsulfaat." Retrieved (http://sieplex.com/article/ammonium sulfate).

Dewaelheyns, Valerie, Annemie Elsen, Hilde Vandendriessche, and Hubert Gulinck. 2013. "Garden Management and Soil Fertility in Flemish Domestic Gardens." *Landscape and Urban Planning* 116:25–35.

Dewaelheyns, Valerie, Elke Rogge, and Hubert Gulinck. 2014. "Putting Domestic Gardens on the Agenda Using Empirical Spatial Data: The Case of Flanders." *Applied Geography* 50:132–43.

Dieleman, Patrick. 2014. "Spuiwater van Luchtwassers Als Kunstmest." *Boer & Tuinder*, March.

Dijkstra, T., J. Krooneman, A. De Vos van Steenwijk, R. Winters, and O. M. de Vegt. 2012. *Integratie van Biogasproductie En Winning van Kunstmestvervangers Uit Dierlijke Mest*.

Dikov, Georgi, Stefan Dörig, Ludwig Hermann, Arturo Marquina, Jana Matysikova, Anders Nättorp, and Kirsten Remmen. 2014. *P-REX D 11.1 Report on Market for Phosphorus Recycling Products*.

DLV Advies, MeMon, and EcoEnergy. 2019. "Groen Fosfaat." Retrieved November 18, 2019 (https://www.dlvadvies.nl/dossier/groen-fosfaat/).

Dodde, Haijo. 2012. "Mogelijk Alternatief Voor Kunstmest." *Nieuwe Oogst*, 21.

EGTOP. 2016. *Final Report on Organic Fertilizers And Soil Conditioners (II)*. Directorate-General for Agriculture and Rural Development.

EGTOP. 2018. *Final Report on Fertilisers (III) Directorate-General for Agriculture and Rural Development*. Directorate-General for Agriculture and Rural Development.

Ehlert, P., P. Hoeksma, and GL Velthof. 2009. *Anorganische En Organische Microverontreinigingen in Mineralenconcentraten*.

European Commission. 2007. *Council Regulation (EC) No 834/2007 of 28 June 2007 on Organic Production and Labelling of Organic Products and Repealing Regulation (EEC) No 2092/91*.

European Commission. 2018. "Council Regulation (EU) 2018/848." 1151:1–92.

European Commission. 2019. *Fertilisers in the EU Prices, Trade and Use Contents*.

European Commission. 2020. "European Green Deal." Retrieved (https://ec.europa.eu/info/files/communication-european-green-deal_nl).

Fagerberg, Britta, E. V. A. Salomon, and Simon Jonsson. 1996. "Comparisons between Conventional and Ecological Farming Systems at Öjebyn: Nutrient Flows and Balances." *Swedish Journal of Agricultural Research*.

Flemish Land Agency. 2020. *Mestrapport 2020*.

GEA. 2010. "Ammonium Sulfate."

GOV. UK, Department of Enviroment, Food and Rural Affairs and Environment Agency. 2018. "Using Nitrogen Fertilisers in Nitrate Vulnerable Zones." Retrieved February 24, 2020 (www.gov.uk/guidance/using-nitrogen-fertilisers-innitrate-vulnerable-zones#contents.).

Harms, Imke, Ivona Sigurnjak, Renata Sultanbaeva, Franky Coopman, Alain Bouthier, Robert Trochard, Romke Postma, Katharina Laub, Anke De Dobbelaere, and Niamh Power. 2019. *D 1.2. Exploring the Demand for Recycling- Derived Nutrients and Organic Matter in Regions of Northwest Europe*.

Hermann, Ludwig and Ralf Hermann. 2020. *D 2.5 Midterm Report on LCA Analysis and Sustainability Indicators of Products (Confidential)*.

de Hoop, JG, CHG Daatselaar, GJ Doornewaard, and NC Tomson. 2011. *Mineralenconcentraten Uit Mest; Economische Analyse En Gebruikerservaringen Uit de Pilots Mestverwerking in 2009 En 2010*.

Huttunen, Suvi, Kaisa Manninen, and Pekka Leskinen. 2014. "Combining Biogas LCA Reviews with Stakeholder Interviews to Analyse Life Cycle Impacts at a Practical Level." *Journal of Cleaner Production*.

Huygens, Dries, Glenn Orveillon, Emanuele Lugato, Sara Comero, Arwyn Jones, and Bernd Gawlik. 2019. *Developing Criteria for Safe Use of Processed Manure in Nitrates Vulnerable Zones above the Threshold Established by the Nitrates Directive-Interim Report-Draft*.

Huygens, Dries, Glenn Orveillon, Emanuele Lugato, Simona Tavazzi, Sara Comero, Arwyn Jones, Bernd Gawlik, and Hans Saveyn. 2020. *SAFEMANURE - Developing Criteria for Safe Use of Processed Manure in Nitrates Vulnerable Zones above the Threshold Established by the Nitrates Directive - Final Report*.

Jacobsen, BH, O. Bonnichsen, and Juan Tur-cardona. 2017. "Danish Farmers' Preference for Bio-Based Fertilisers - a Choice Experiment." *Peer Review Papers* 1.

Jensen, Lars Stoumann, Chris Thornton, Patrick J. Forrestal, Jeanet Brandsma, Airi Külvet, Kaisa Riiko, and Christian Kabbe. 2016. *Mini-Paper – End-User Requirements for Recycled and Bio- Based Fertiliser Products*.

Kaffka, Steve and Herbert H. Koepf. 1989. "A Case Study on the Nutrient Regime in Sustainable Farming." *Biological Agriculture and Horticulture*.

Kirchmann, H., M. H. Ryan, and L. Bergström. 2008. "Plant Nutrient Use Efficiency in Organic Farming - Consequences of Exclusive Use of Organic Manures and Untreated Minerals." *CAB Rev: Perspect Agricul Vet Sci, Nutr Natural Res* 2(076)(12).

Kirchmann, Holger, Lars Bergström, Thomas Kätterer, Lennart Mattsson, and Sven Gesslein. 2007. "Comparison of Long-Term Organic and Conventional Crop-Livestock Systems on a Previously Nutrient-Depleted Soil in Sweden." in *Agronomy Journal*.

Van der Knaap. 2019. "Wepage Research and Development." Retrieved (https://www.vanderknaap.info/nl/innovatie/research--development?ybcookie=approve).

Van der Knaap, Opure, Triqua International, and Forteco Services. 2018. "Productie Glastuinbouw-Nutriënten Uit Mest."

Knuivers, Martijn. 2013. "Teler Experimenteert Met Spuiloog in de Rij." *De Boerderij*.

Lebuf, Viooltje and Sara Van Elsacker. 2015. *Potentieel Voor Mestafgeleiden Als Grondstof in de Minerale Meststoffen- of Chemische Industrie*.

Leenaerts, Sofie. 2011. "Fosfaatrecuperatie : Studie van de Mogelijke Afzetmarkten."

Lloyd's Register. 2017. *Zero-Emission Vessels 2030 . How Do We Get There ?*

Lockeretz, William, Georgia Shearer, Susan Sweeney, George Kuepper, Diane Wanner, and Daniel H. Kohl. 1980. " Maize Yields and Soil Nutrient Levels With and Without Pesticides and Standard Commercial Fertilizers 1 ." *Agronomy Journal.*

Mattsson, L. and T. Kjellquist. 1992. "Nitrogen Fertilization to Winter Wheat on Farms with and without Animal Husbandry." *Report No 189*.

Möller, Kurt, Johann Habermeyer, Volker Zinkernagel, and Hans Jürgen Reents. 2006. "Impact and Interaction of Nitrogen and Phytophthora Infestans as Yield-Limiting and Yield-Reducing Factors in Organic Potato (Solanum Tuberosum L.) Crops." *Potato Research*.

Muller, Adrian, Christian Schader, Nadia El-Hage Scialabba, Judith Brüggemann, Anne Isensee, Karl Heinz Erb, Pete Smith, Peter Klocke, Florian Leiber, Matthias Stolze, and Urs Niggli. 2017. "Strategies for Feeding the World More Sustainably with Organic Agriculture." *Nature Communications*.

Notenboom, G., S. Helmyr, and E. Van der Zandt. 2017. *Top 5 Grondstoffen:Van Aanbod Tot Vraag*.

Olson, N. and J. Holbrook. 2012. *NH3- the Other Hydrogen Tm*.

Oost, Netwerk Luchtwassers Gelderse Vallei/Utrecht. 2009. "Spuiwater Geeft Grasgroei!"

Power, Niamh and Aiofe Egan. 2020. *Deliverable 4.2 Desired Properties of Recycling- Derived Fertilisers from an End- User Perspective*.

Power, Niamh, Vesna Jaksic, Imke Harms, and Katharina Laub. 2019. "Renu2Farm: Closing the Nutrient Cycle:

What Are the Properties Required by Farmers, to Encourage the Use of Recycling-Derived Fertilisers in North West Europe?"

Reimer, Marie, Tobias Edward Hartmann, Myles Oelofse, Jakob Magid, Else K. Bünemann, and Kurt Möller. 2020. "Reliance on Biological Nitrogen Fixation Depletes Soil Phosphorus and Potassium Reserves." *Nutrient Cycling in Agroecosystems* 0123456789.

Reubens, Bert (ILVO) and Koen (ILVO) Willekens. 2012. "Beschikbaarheid En Gebruik van Biologische Dierlijke Mest in Vlaanderen: Actuele Situatie En Toekomstperspectief. Deelrapport 3 van Het ADLO-Onderzoeksproject Optimale Aanwending van Biologische Mest van Kippen En Herkauwers Voor Een Gezond Biologisch Gew." (December):85.

Rigby, Hannah and Stephen R. Smith. 2011. *New Markets for Digestate from Anaerobic Digestion*.

Rombouts, G., K. Reyns, L. Gallopyn, K. Cochez, K. Van Hoof, and A. Huysmans. 2014. "Praktijkgids Bemesting." 115.

Röös, Elin, Axel Mie, Maria Wivstad, Eva Salomon, Birgitta Johansson, Stefan Gunnarsson, Anna Wallenbeck, Ruben Hoffmann, Ulf Nilsson, Cecilia Sundberg, and Christine A. Watson. 2018. "Risks and Opportunities of Increasing Yields in Organic Farming. A Review." *Agronomy for Sustainable Development*.

Ryan, M. H. and J. F. Angus. 2003. "Arbuscular Mycorrhizae in Wheat and Field Pea Crops on a Low P Soil: Increased Zn-Uptake but No Increase in P-Uptake or Yield." *Plant and Soil*.

Ryan, M. H., J. W. Derrick, and P. R. Dann. 2004. "Grain Mineral Concentrations and Yield of Wheat Grown under Organic and Conventional Management." *Journal of the Science of Food and Agriculture*.

Seveso-inspectiediensten, Belgische. 2009. *Inspectie-Instrument Ammoniumnitraat*.

Smit, C. T., H. Prins, and Hoop. 2000. *Quick Scan Naar Afzetperspectieven van Mest En Mestproducten*.

Teagasc, Jonstown Castle, and Environment Research Centre. 2016. *Major & Micro Nutrient Advice for Productive Agricultural Crops*.

Tur-Cardona, Juan, Ole Bonnichsen, Stijn Speelman, Ann Verspecht, Louise Carpentier, Lies Debruyne, Fleur Marchand, Brian H. Jacobsen, and Jeroen Buysse. 2018. "Farmers' Reasons to Accept Bio-Based Fertilizers: A Choice Experiment in Seven Different European Countries." *Journal of Cleaner Production* 197:406–16.

Tur-Cardona, Juan, S. Speelman, A. Verpecht, and J. Buysse. 2015. "Farmers ' Reasons to Accept Bio-Based Fertilizers – A Choice Experiment in Flanders." Pp. 8–11 in *16th Ramiran International Conference*.

Tur-cardona, Juan. 2015. "Farmers' Reasons to Accept Bio-Based Fertilizrs: A Choice Experiment in 8 European Countries."

Vaneeckhaute, Céline. 2015. "Nutrient Recovery from Bio-Digestion Waste: From Field Experimentation to Model-Based Optimization."

Vannecke, Thomas, Annelies Gorissen, and Helena Vanrespaille. 2018. *Literatuurstude: Waarde van de Dikke Fractie Na Mestscheiding Als Bron van Organische Stof*. Brugge: Vlaams Coördinatiecentrum voor Mestverwerking.

VCM. 2020. *Results on Operational Capacity Manure Processing in Flanders*.

VCM and Fraunhofer IGB. 2015. *Recuperatie van Fosfor Uit Varkensmest En Digestaat*.

Velthof, G. 2011. "Kunstmestvervangers Onderzocht:Tussentijds Rapport van Het Onderzoek in Het Kader van de Pilot Mineralenconcentraten."

Velthof, Gl. 2011. *Synthese van Het Onderzoek in Het Kader van de Pilot Mineralenconcentraten*.

Veltman, Alex. 2012. "Pilotonderzoek Op de Rioolwaterzuivering Amsterdam West, Struviet Productie Door Middel van Het Airprex Proces." 46.

Verkerk, Hans. 2016. "Fosfaatmeststof Terug Op Derogatiebedrijven." *Grondig*, 47.

VLACO. 2016. *Ecologische En Economische Voordelen Digestaat*.

Yara. 2020. "Yara Ready to Enable the Hydrogen Economy with Historic Full-Scale Green Ammonia Project." *Corporate Releases*. Retrieved (https://www.yara.com/corporate-releases/yara-ready-to-enable-the-hydrogen-economy-with-historic-full-scale-green-ammonia-project/).

Yara International ASA. 2017. *Position Paper on Circular Economy*.

I. ANNEX I Niche markets

This chapter gives an overview of current and future potential niche markets and the barriers still to overcome before recovered nutrients can be successfully made available on the market.

Entering these markets usually takes a lot of research, testing, finetuning of product, logistics, negotiating, etc. but can eventually render much higher profit margins and encounters less competition.
This is a time-, money- and energy consuming process for which most biogas plants don't have the resources nor are experienced for. Entering these niche markets will need the support of universities, research facilities, consultants, private corporations, funding etc.

I.1 Nutrient source in biological water treatment

Ammonia is used in several areas of water and wastewater treatment, such as pH control, in solution form to regenerate weak anion exchange resins, in conjunction with chlorine to produce potable water and as an oxygen scavenger in boiler water treatment.
Industrial waste water treatment with activated sludge (nitrification-denitrification) sometimes has to cope with lower COD removal efficiencies and floating sludge due to shortage in nutrients (N,P, micronutrients). This is seen in pulp-and paper industry wastewater ("white water"), forest industry wastewater treatment and in sectors where a lot of process water going to the wastewater treatment. Therefore, urea (40%) and phosphoric acid (75%) are dosed as macronutrients. The amount depends on the amount of COD in the influent.
Recovered nutrients (N and P) can be cheap alternatives for these industries.
Some companies can be afraid to try these "new" recovered nutrients, because their activated sludge system can be sensitive to contaminants, chemicals, detergents or peaks in COD. Tests at lab scale with their active sludge could be necessary to persuade them that the recovered nutrient products are not toxic for their active sludge and the required permits (e.g. resource declaration) should be requested.

Examples

A beverage industry only treating relatively small amounts of wastewater (e.g. 30m³/day) and COD requires only 0,36 L of Phosphoric acid (75%) and 6,6 L of urea (40%) per day. Replacing this with ammonia water (15%) would mean 22 L ammonia water/day. If mineral concentrate (6,12 g N/kg and 0,17 g P/kg) would be used, 190 L should be supplied. This would fill in 25% of the amount of P required as a macro nutrient.

A paper industry treating 200 m³/hour uses 80m³ of urea per week and 20m³ of phosphoric acid per month. Using ammonia water to complete the N demand would require 68m³ ammonia water (15%) per week or 590m³ of mineral concentrate.

A wastewater treatment from a chemical company treating 500 m³/hour uses 0,5m³ of urea and 2L of phosphoric acid per day. Using ammonia water to complete the N demand would require 1,7m³ ammonia water (15%) per day or 14m³ of mineral concentrate.

I.2 Chemical industry

In 2018, ammonium sulphate was used mainly (95% of world consumption) as a nitrogen fertiliser material. Industrial use of ammonium sulphate accounts for only about 5% of world consumption.
Ammonium sulphate is produced as a crystal by three different processes: (1) synthetic manufacture from pure ammonia and concentrated sulfuric acid, as a by-product of gas cleaning in coke and coal gasification plants, (3) from ammonia scrubbing of tail gas at sulfuric acid (H2SO4) plants, and (4) as a by-product of the production of caprolactam ((CH2)5COHN), Methyl Methacrylate and acrylonitrile (GEA 2010).

Recently, the world-wide supply of ammonium sulphate has increased somewhat, in part due to the production of ammonium sulphate by direct reaction crystallization from (spent) sulfuric acid and ammonia. The additional production capacity of ammonium sulphate has not been sufficient to satisfy the market requirements, therefore there is still room for recovered ammonium sulphate (GEA 2010).
As one might expect, the price of ammonium sulphate varies with the purity and particle size of the crystals, i.e. small crystals (< 1mm) are worth 3 times less than larger "granular" ones (2-3 mm).

Other industrial applications include leather, textiles, flame retardants. In baking applications, it functions as a dough conditioner and dough strengthener in bread products. It supplies nitrogen to the yeast for nourishment aiding in yeast function while promoting browning. It is recognised as a food additive (E515) in the EU and therefore it should be food grade quality and the legal constraints (i.e. end-of-manure status) probably still hinder its use as food additive.

Ammonium nitrate(AN) is used as hardener in the production of fibreboards and MDF. In the production of fibreboards, a long processing time is needed for mixing the raw material (wood) and the glue. Also, the adhesive must dry quickly during pressing to achieve a high production speed. This is possible by adding a temperature-sensitive hardener to the adhesive. As hardeners, ammonium salts, such as ammonium nitrate, sulphate, etc. are usually added to the glue (except for PF glue).
The release of acids lowers the acidity (pH), which promotes the drying of the glue. The choice and amount of hardener depends on the process conditions. Without the addition of a hardener, the number and complexity of the process conditions increases. In order to slow down the drying before pressing, ammonia is added as buffer substance.
Some producers of wood boards have expressed interest in AN solution or crystals as secondary raw material. Sometimes ammonium sulphate is used because this is cheaper, but AN is preferred because it is more stable and performant.
Yet, they require the product to have no impurities and they cannot specify which elements exactly are considered as impurity. Therefore, they would like to do some tests with the product (minimum 40%N) first and they would currently they need 3000 ton AN solution/year and no minimum volume supply is required.
If the product meets the requirements, a competitive price has to be negotiated.
Ammonium nitrate solutions with more than 28% nitrogen by weight compared to ammonium nitrate must successfully pass the detonation test defined in (EC) Regulation n° 2003/2003 In order to be free in circulation in the internal market (Seveso-inspectiediensten 2009). They must also meet a certain number of technical requirements regarding their porosity, the size of the particles, the pH and the percentage of impurities (e.g. a very low limit for organic substances).
Ammonium nitrate could be a precursor for explosives when the water is removed by evaporation (Regulation (EU) No 98/2013 on the marketing and use of explosives precursors). Again, a very high purity is required which may be a limiting factor. Recovered ammonium products typically have a strong odour.

I.3 Ammonia as an energy carrier

I.3.1 Solid Oxide Fuel Cells

Fuel cells provide an opportunity to develop thermodynamic systems that generate electricity on the basis of electrochemical reactions by consumption of reactants from external sources. Moreover, fuel cells are recommended because of their high efficiency, low environmental footprint and attractive technology for the direct conversion of fuel to electricity.
Among these different types of fuel cells, Solid Oxide Fuel Cells (SOFC) have a big advantage on combination of environment-friendly power generation with fuel flexibility. In recent years, ammonia (NH3) has emerged as a promising fuel for electricity generation in SOFCs (Afif et al. 2016).
Considering the electrolyte and electrodes, the direct ammonia-fed SOFC-H is the most promising energy source for next-generation fuel-cell technology. However, its development is not yet at the commercialization stage and further investigation is required.

I.3.2 Internal combustion engine

Ammonia has been proposed as a practical alternative to fossil fuel for internal combustion engines (Olson and Holbrook 2012). Ammonia was used during World War II to power buses in Belgium, and in engine applications prior to 1900.
Since ammonia contains no carbon, its combustion cannot produce carbon monoxide, hydrocarbons or soot and high compression ratios prevent NOx production (David et al. 2014).
However, ammonia is a much less active fuel compared to gasoline, it doesn't combust easily on its own. But, with a small amount of combustion enhancer (gasoline, diesel or pure hydrogen) mixed in, it burns and releases enough energy to drive the engine. A prototype of an NH3 car has already been built, equipped with a control system that makes the perfect mixture with combustion enhancer (gasoline, diesel or pure hydrogen), which burns and releases enough energy to drive the engine on NH3 with a radical reduction in carbon and greenhouse gas emissions (http://www.nh3car.com/how.htm).

However, alternative fuels first have to overcome a technology-change cost (CAPEX) hurdle, which, for the incumbent fuel, is always zero (Lloyd's Register 2017).
This underlines the importance of policy and regulation as drivers for change, since market forces alone appear unlikely to prove sufficient.(Brown 2017)
Still, some entities in the maritime sector operate in unique, niche markets where ammonia fuel technologies are already competitive, and they have an unrivalled opportunity – today – to deploy these technologies (Brown 2017).

I.4 Ammonia as a hydrogen carrier

There is a demand for ammonia as a hydrogen carrier (reductant) in emerging emission control (DeNOx) technologies in industrial and automotive applications.
Selective (non-)catalytic reduction for flue gas cleaning of NOx is used in a wide range of capacities in all kinds of combustion installations in sectors like waste incineration, energy plants, metal industry and greenhouse horticulture. The scrubbing process is also used to remove NOx from NOx rich gases produced in a relatively small amount at metal-dissolving, nitric acid and chemical plants, etc. (Anon n.d.).
Selective (Non-)Catalytic Reduction reduces NOx (the oxides of nitrogen) to N2 and H2O by adding NH3 or urea according to the following this reaction diagram:

$$4NO + 4NH_3 + O_2 \rightarrow 4N_2 + 6H_2O$$
$$2NO_2 + 4NH_3 + O_2 \rightarrow 3N_2 + 6H_2O$$

I.4.1 Selective non-catalytic reduction (SNCR)

In SNCR, a mixture of steam and the reducing agent is injected in the flue gas of an incineration process, to the furnace. If ammonia is used as reducing agent, the optimal temperature is 930 to 980°C. If urea ($(NH_2)CO$) is used, the temperature needs to be even higher (950-1050°C) because it needs to be thermally cracked to NH3, which can then react as the reducing agent.
NOx removal efficiencies in SNCR range from 40 to 70% (Anon n.d.) .

Example

An incineration plant that processes 25 tonnes of waste an hour, emits 25 to 40 kg NOx/h. To reduce the NOx below the limit of 120 mg NOx/Nm³ this would require 100 L of ammonia solution (25% chemical grade). At a cost of 150€/ tonne of ammonia solution this would mean a yearly cost of 14.000€. A larger incineration plant claimed to use 1000 tons ammonia solution (25% chemical grade) per year, costing them 150.000€/year. Recovered ammonia water (10-20%) is perfectly suited to replace urea.

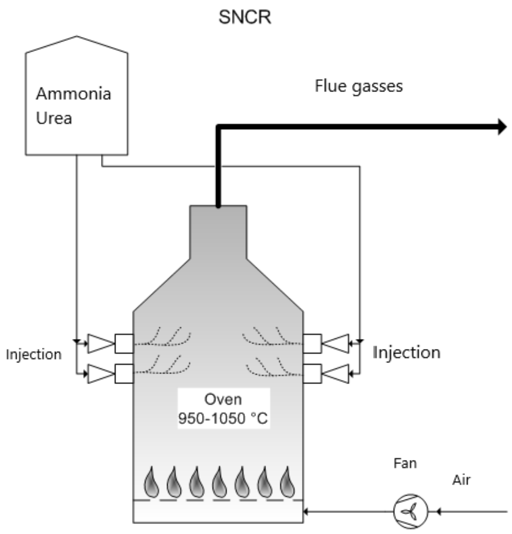


Figure I-1. Scheme SNCR (Emis: energie- en milieu-informatiesysteem voor het Vlaamse Gewest n.d.)

There are already waste incineration companies using only recovered ammonia water in their DeNOx process and have not had any problems with it. Lower concentrated ammonia water (10%) can also be used, because different concentrations of recovered ammonia water can be blended in one storage tank before usage.
Impurities in the recovered ammonia water are no issue for SNCR since there is no catalyst present which could be fouled.
In general, most incineration plants are not inclined to use the recovered N alternative, because this cost of contaminant free 25% urea solution is only marginal for them.
They could be persuaded to use (lower quality) ammonia water for their flue gas cleaning (SNCR), if they can obtain it for a low price.
If only transport costs are taken into account, both parties (the biogas plant and the incineration plant) are reducing their costs.

I.4.2 Selective catalytic reduction (SCR)

SCR is using a catalyst to accelerate the deNOx process and improve the efficiency. The optimum process temperature lies between 320 – 500 °C depending on the catalyst (oxides of vanadium, wolfram, molybdenum or other metals).

NOx removal efficiencies with SCR range from 80-95% (Anon n.d.) with incoming concentrations of NOx of some g/Nm³ up to 1 000 000 Nm3/h. This is a higher NOx reduction yield compared to SNCR. Smaller installations (<5MWth) have a lower yield (80-85%).

The SCR installation can be placed immediately after the boiler ("high-dust" switching) or after the dust filters or scrubbers ("low-dust" switching). This requires the flue gas to be heated to reaction level. The ammonia source is injected into the exhaust gases prior to their passing into the SCR (Chironna and Altshuler 2001).

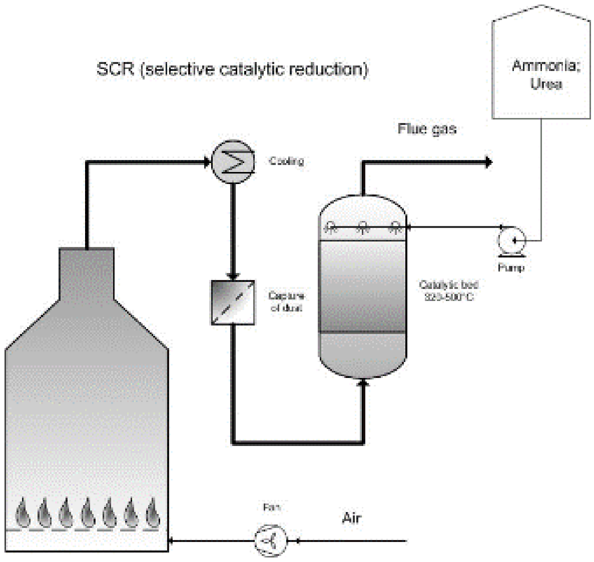


Figure I-2. Scheme SCR (Emis: energie- en milieu-informatiesysteem voor het Vlaamse Gewest n.d.)

The use of recovered ammonia water as a reducing agent would also be possible in SCR but requires a higher purity because of the presence of the catalyst. The following components must not be present in that the recovered ammonia water:

- SO_3 and Cl, since they react with ammonium and water to form ammonium sulphate, ammonium bisulphate and ammonium chloride. These condensed ammonium salts can cause reversible deactivation of the catalyst, by lowering the active surface of the catalyst and hereby reducing its separation efficiency. They are emitted as aerosols that are difficult to separate.
- Dust, because it contains potassium and sodium, which can precipitate on the catalyst causing poisoning or irreversible deactivation of the catalyst.

Some ammonia solutions recovered from bio-waste can already meet these quality specifications (personal communication, 2018). Yet, plants using SCR are reluctant on using recovered ammonia water because, the flue gas cleaning process is far from their core business, and the reduced costs related to the recovered ammonia solution are relatively small compared to the risk they would take by poisoning their catalysts.

The use of recovered ammonia water could also help contribute to the green image of the plant and reduce the costs of buying chemical grade ammonia. If the whole chain (biogas plant, provinces, incineration plants of municipal waste) could be involved, this could facilitate the logistic and supply aspect and raise more public awareness about recycling.

I.4.3 SCR as deNOx for exhaust gasses from combustion engines

In the European Union emissions of nitrogen oxides (NOx), must be limited by EU exhaust emissions standards and Real Driving Emissions legislation. One in two new cars registered in Western Europe is a diesel vehicle, which means the number of cars with SCR technology is set to rise.
The SCR reaction is the same as described above, the reducing agent is called "Diesel exhaust fluid (DEF)" better known under the commercial name "AdBlue®" or AUS32 under the ISO 22241. DEF is an aqueous urea solution made with 32.5% urea and 67.5% deionized water.

ISO 22241 lists strict requirements for maintaining concentration and purity of ingredients critical to the proper functioning and longevity of the SCR system. It also contains a description on the methods to be used for determining these parameters and reproducibility of the results.

An important phrase in the ISO 22241 states that AUS 32 is an aqueous urea solution, manufactured from technically pure urea – with no addition of any other substances – and pure water. Technically pure urea is industrially produced grade of urea with traces of biuret, ammonia and water only. The specifications of AUS 32 are listed in Table I-1.

Table I-1. Specifications for AUS32 in ISO22241

Characteristics	Unit	Min	Max
Urea content	% (m/m)	31.8	33.2
Density at 20°C	Kg/m³	1087.0	1093.0
Refractive index at 20°C		1.3814	1.3843
Alkalinity as NH3	%(m/m)		0.2
Biuret	%(m/m)		0.3
Aldehydes	Mg/kg		5
Insoluble matter	Mg/kg		20
Phosphate (PO4)	Mg/kg		0.5
Calcium	Mg/kg		0.5
Iron	Mg/kg		0.5
Copper	Mg/kg		0.2
Zinc	Mg/kg		0.2
Chromium	Mg/kg		0.2
Nickel	Mg/kg		0.2
Aluminium	Mg/kg		0.5
Magnesium	Mg/kg		0.5
Sodium	Mg/kg		0.5
Potassium	Mg/kg		0.5

The strict requirements of the composition and purity of AUS 32 described in the ISO 22241 make it practically impossible for recovered ammonia water to be used as such as AUS 32. Even if a purity similar to AUS 32 could be reached by upgrading, ammonia water would still not contain urea (but ammonium).

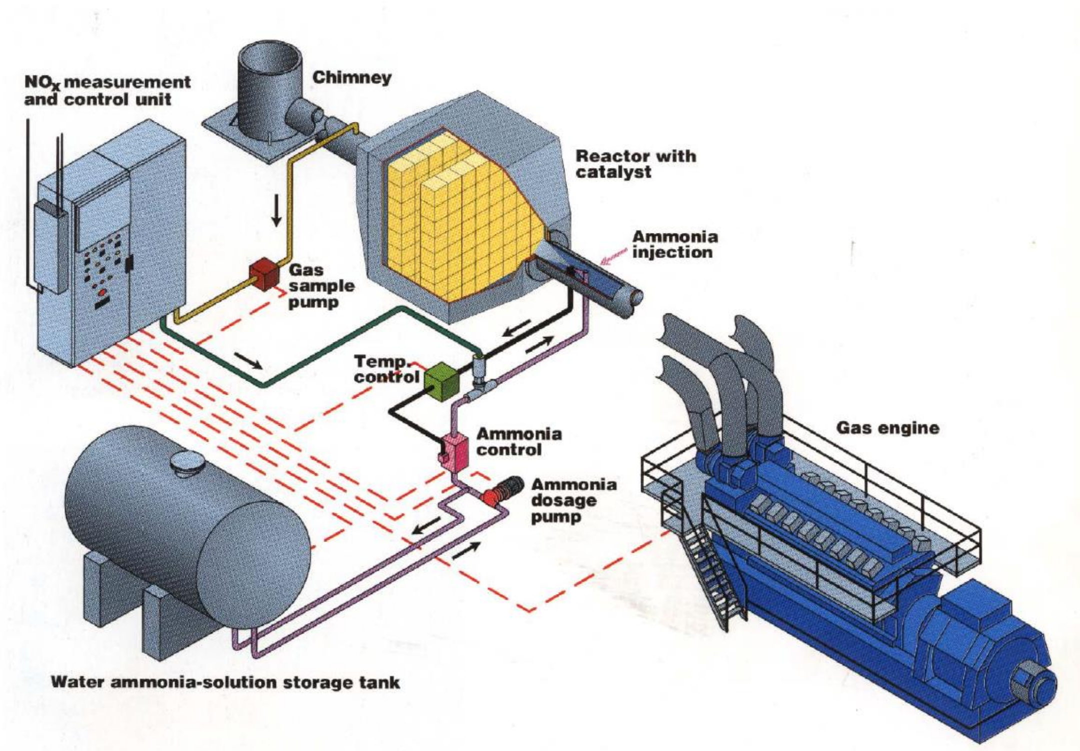
It would also not be possible to sell it under the name "AdBlue®" and suppliers of SCR systems would not want to use this product in their systems, since it does not meet the ISO22241 specifications and therefore they cannot give guaranties on its performance.
However, the European Emission Standards do not mandate the use of specific technologies (and products) to meet the standards.
So, there is a prospect for recovered ammonia water being used as DEF, but only if it is proven to work with a certain SCR technology and could pass all safety requirements for quality, handling, testing, transportation storage, and refilling.

Furthermore, it would be very difficult to be competitive in the AUS 32 market, since AdBlue® is produced in large quantities and sold with a profit margin of only a few €cents per litre (personal communication, 2018). This makes it even for the large manufacturers difficult to produce a competitive product and they can sometimes only achieve this by having the do this by having their producing facilities on the most opportune locations. The easiest way to use recovered ammonia as AUS 32 would be by supplying it to a producer of AUS 32 as secondary raw material.

Gas engines on natural gas or other fuels (e.g. biogas) are used more frequently as emergency power supply. The NOx emission limit for gas engines on natural gas and biogas is 190mg NOx/Nm³ (https://www.amps.org.uk/eu-emissions-update). NOx excess can again be removed with an SCR gas cleaning system using a urea solution as reductant.

To be an eligible alternative reductant for SCR, the purity of the products needs to be proven before it can be used. Also, a file needs to be made to get a resource declaration from the ruling authorities for this specific product application. The file should scientifically substantiate that the product is suited for this application. It should also describe the composition and purity required to guaranty the safety for the SCR process.

Figure I-3.SCR in gas engine. Source: Wärtsila Nederland



II. ANNEX II Success stories

II.1 YARA synergies

In Norway, mineral fertiliser producer Yara cooperates with the VEAS wastewater treatment plant in Oslo, which produces ammonium nitrate by stripping the ammonium from the wastewater.

The plant was originally designed for sulphuric acid but in 1998 it switched to 55% nitric acid because farmers said they did not want ammonium sulphate because of its acidifying effect on soil. Furthermore, Norsk-Hydro (now Yara) was prepared to supply nitric acid and purchase the ammonium nitrate, which relieved VEAS of finding customers for its recovered N. This synergy is convenient for both parties.

However, ammonium nitrate is a powerful oxidising agent and in the presence of organic matter is liable to explode. Consequently, Yara has set a quality limit of 100 ppm total organic carbon. On occasions the TOC-limit has been difficult to achieve, but mostly the product is acceptable to Yara. The economics of the process lie in this control program and in optimising the air flow. At least 90% of the ammonia is air-stripped and recovered from the filtrate. VEAS produces about 3000 tonnes ammonium nitrate (dry weight) per year.
Yara uses the ammonium nitrate for the manufacturing of calcium nitrate or sells it to the wood industry (Yara International ASA 2017).
The plant manager estimates the cost for replicating the plant (wastewater treatment for 650,000 people equivalents) on 586,000€.
Other Yara plants that could use ammonium nitrate are:

- Sluiskil in the Netherlands. This plant produces N fertilisers and industrial chemicals.
- Tertre near Mons in Belgium. This plant produces nitrogen fertilisers for markets in France, Germany, Belgium and the Netherlands as well as industrial chemicals - ammonia, aqueous ammonia, ammonium nitrate and nitric acid - for European industrial customers.
- Vlaringen near Rotterdam. This plant produces niche products like potting soil fertilisers. In this rare case, there can also be a market potential for bulk liquid ammonium nitrate. Since, the Yara plant is located on less than 50km from Westland greenhouse, which uses high quality liquid fertilisers, transport cost are relatively low, making this an interesting sales opportunity.

II.2 Magic dirt®

In the US there is a growing trend of digestate products making strides at penetrating the horticulture and agriculture markets.
Magic Dirt™ (https://www.magic-dirt.com/), a potting soil produced exclusively from DVO's digestate in the USA and sold by Walmart in 2,500 outlets is an excellent example for how a digestate-based product could be marketed. Magic Dirt™ is formulated with anaerobically digested organic fibre and composted forest products. It is not compost, and it contains no peat moss, coir, perlite or vermiculite.
The products are certified under the USDA's BioPreferred Program as 100% BioBased (all organic ingredients). This does not mean that the product would be accepted for organic farming in Europe, but it may be a very viable pathway for achieving a high market value – the retail value in the US is about 700 USD/ton. The barriers for producing products like Magic Dirt™ from SYSTEMIC demonstration plants are most likely the number of supply sources and the homogeneity of products – DVO has more than 120 similar plants using mainly cow manure as feedstock and consequently producing a large quantity of a quite homogenous product. Walmart and blenders would probably not be interested to start such an activity with only one source of supply. But as soon as a project pipeline would demonstrate growing potential, similar business cases should be possible in Europe.

II.3 Van der Knaap

In the past seven years, the Dutch company Van der Knaap and partners Opure, Triqua International and Forteco Services, have been developing a fertiliser solution derived from digestate. The technique has been patented, and together with Wageningen University and Research trials have been done on cucumber cultivation.

The technology cascade looks as follows:

- Digested pig slurry is separated in a solid and liquid fraction.
- From the liquid fraction calcium and Magnesium -phosphorus salts are precipitated after addition of Mg and Ca.
- Biological nitrification converts ammonium to nitrate
- Potassium carbonate is added, forming potassium nitrate, which is concentrated together with humic acids by means of membrane filtration
- With nanofiltration the fulvic acids are extracted
- By means of RO an NPK fertiliser solution is obtained, next to permeate rich in salts.

(Van der Knaap 2019; Van der Knaap et al. 2018, Groenten Nieuws/Van der Knaap, 2020)

II.4 Crystal Green®

The production of Crystal Green® by the company Ostara, is a good example of a fully developed value chain for a recovered phosphorus from wastewater.
Ostara's fluidized bed reactor (the Pearl® reactor) produces struvite pellets from digested wastewater treatment sludge. The pellets are dried and classified on site in different specific pellet sizes.

Ostara provides the technology and design of the reactor and takes care of the process technological quality control to be able to guarantee the constant quality of the struvite salts. They collect the different pellet sizes, packages and markets them as Crystal Green® (N-P-K: 5-28-0 + 10% Mg), a high purity, slow-release mineral fertiliser (Ceulemans and Schiettecatte 2013; Notenboom et al. 2017). Normally, struvite is not soluble in water, but by stimulating the citrate production of the germinating plant roots Crystal Green® releases more phosphate per application (Colenbrander 2018).
The operational costs for the Pearl® process are completely covered by the sales of Crystal Green®.

Crystal Green® is certified in the UK as EG fertiliser and can be used in the Netherlands within a derogation (Colenbrander 2018). It is also REACH certified and meets with the standards of the European fertiliser regulation.

The wastewater treatment plant in Amersfoort (NL) has a Pearl reactor® since 2016 and the pellets are marketed via Agro-Vital Groningen for 2,5€/kg (Ceulemans and Schiettecatte 2013; Leenaerts 2011).

II.5 Recovered phosphate products allowed as P fertiliser under derogation in the Netherlands

A few years ago, official negotiations put an end to the use of mineral phosphate fertilisers on derogation farms in the Netherlands, with the result that the useful P starter fertilisation (e.g. for corn), was not allowed anymore.
After some lobby work, 2 alternatives for mineral P fertiliser are allowed (i.e. derogation) to be applied for row fertilisation of silage maize, on plots with a low phosphate status.

Figure II-1. Green Phosphate pellets.

Groen Fosfaat® (English: Green Phosphate) is an organic phosphate fertiliser with a favourable nutrient ratio produced from animal manure. For nitrogen, the fertiliser does count as animal manure in manure accounting balance, since it contains nitrogen from animal manure, which is also limited to 170 kg/ha/year. Green phosphate is sold for 300€/ton, the price fluctuating according to the place of delivery. For now, the market for Green Phosphate is still marginal (DLV Advies, MeMon, and EcoEnergy 2019).

Figure II-2. Physiostart P Plus micro-granulates.

Micro-granulates for precision fertilisation, containing mineral P, were also not allowed to be used on Dutch derogation enterprises. Producer Timac Agro went looking for an alternative to the mineral P for its start fertiliser Physiostart. After some research and testing, they created Physiostart P Plus, with recovered P (Mg-struvite), which is -like Green Phosphate- allowed to be used on derogation farms (Verkerk 2016).

II.6 P-poor soil improver

Fibrous organic products recovered from manure or digestate may serve as an alternative for peat in potting soil for the consumer market.
A potentially suitable material is currently produced by Groot Zevert Digestion in Beltrum, The Netherlands, where the solid fraction of co-digested manure is separated into organic fibrous fraction and a P fertiliser by using acid and base.
A fibrous material from manure or digestate that meets all these criteria can be sold to the potting soil industry for a price of about € 10-15 m^3 which is generally higher than the market value of soil amendments. This may compensate the costs made to meet the criteria of the potting soil industry.

II.7 Synergy between Groot Zevert Vergisting & Group Op de Beeck

In Chapter 3.1.4, the Pilot in the Netherlands "Mineral Fertiliser Free Achterhoek" was described. To comply with the conditions for the pilot status posed by the ministry, the "Green Meadows Fertiliser" (GMF) had to consist out of a certain percentage of recovered nitrogen. During start-up phase in spring 2019, the nitrogen concentration of the GMF was not obtained and GZV went looking for recovered ammonia to boost the N content of their fertiliser solution. SYSTEMIC Associated Plant Group Op de Beeck (Belgium) produces ammonia water from digestate of bio-waste. ADR[5] transport was arranged to GZV in Beltrum (NL). Ammonia water could be transported across the Dutch border as a product with only a CMR[6] transport- document because it also has been certified by Vlaco[7] to be used as soil improver/fertiliser (personal communication, 2019).
At the GZV plant, two loads of 150m^3 of 20% ammonia water were unloaded via a direct stainless-steel piping to a mixing tank, where it was mixed with GMF (4% of the total volume) to boost the nitrogen concentration up to 1,5%.

[5] **A**ccord européen relatif au transport international des marchandises **D**angereuses par **R**oute
[6] **C**onvention relative au contrat de transport international de **m**archandises par **r**oute
[7] Vlaamse Compost Organisatie; EN: Femisch Compost Organisation

II.8 ICL Fertilisers Amsterdam using struvite from Waternet

Waternet's Amsterdam West wastewater treatment plant treats the wastewater of more than 1 million inhabitants in the Netherlands. Since 2006, 600.000 tons of sewage sludge per year are digested on site creating green energy. The digestate is dewatered by a centrifuge,
Yet, a few years ago a massive build-up of struvite crystals (N-P-K, 5-28-0) in the sludge holding tank, centrifuge and the pipelines was discovered, causing wear and tear on the centrifuge. Two important factors where causing this struvite deposition.

Figure II-3. Struvite depositions in the pipes of the sludge holding tank.

1. The phosphorus captured in the biomass of the bacteria was released during anaerobic digestion and reacted with the present ammonium to form Mg-struvite.
2. The design of the digester, stripping CO_2 through turbulence favoured the formation of struvite crystals by a pH rise, pushing the equilibrium towards struvite formation.

After a long procedure of testing, Waternet build the AirPrex® system, that precipitates 95% of the ortho-phosphate as struvite in a controlled way in a reactor after adding 32% $MgCl_2$.
Today, Waternet Amsterdam produces 500-900 ton struvite per year. This is sold to ICL Fertilisers Europe (50-100€/ton), also located in Amsterdam, using it as resource for the production of tailor made fertilisers (Veltman 2012).

Figure II-4. Recovered Struvite.

Waternet is owned by the municipality of Amsterdam which has high ambitions in terms of circularity and P-recovery. Currently, only 20% of the total phosphorus present in the digestate can be recovered as struvite and they aim to increase the percentage of P recovered from their sludge. 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.

II.9 NDM

NDM is a large biogas plant, located in Velen, District Borken in Germany. The region has to cope with nutrient surpluses (mainly from liquid manure) through intensive livestock farming. In July 2014, NDM's current managing director, Doris Nienhaus, developed a concept idea for a biogas-nutrient recycling plant running on regional manure (District of Borken).
Together with ENVIMAC Engineering GmbH and e4 Architekten the project grew in 12 months to a model for modern agriculture.

The aim of the biogas-nutrient recycling plant was to make an important contribution to reducing the manure surplus in the district of Borken by the practical development of environmental technologies for the treatment of manure. In particular, to make marketable concentrated end products which contain recovered valuable substances (N, P, K, organic matter) in a way that no (new) waste streams are created.
The end products produced by the system are solid fraction of manure, ammonium sulphate solution and phosphorus rich ashes (from incinerated solid fraction) which can be blended together in preferred ratios.
The plant is operational since 2019. The digesters are fed with 100% manure, i.e. approximately 100.000 t pig manure per year and 100.000 t cattle manure/year. The manure is supplied by 90 founding members, all farmers from the Borken district.
These farmers have laid the foundations of their joint venture which includes the responsibility for risks, entrepreneurial commitment and, last but not least, equity capital of around 2.4 million euros). The project is considered unique in Europe (https://www.ndm.company/, personal communication, 2018).

SYSTEMIC
Circular solutions for biowaste

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

Consortium

Wageningen University and Research (NL)
AM Power (BE)
Groot Zevert Vergisting B.V. (NL)
Acqua & Sole S.r.l. (IT)
RIKA Biofuels Development Ltd. (UK)
GNS Gesellschaft für Nachhaltige Stoffnutzung mbH (DE)
A-Farmers Ltd (FI)
ICL Europe (NL)
Nijhuis Water Technology (NL)
Proman Management GmbH (AU)
Ghent University (BE)
Milano University (IT)
Vlaams Coördinatiecentrum Mestverwerking (BE)
European Biogas Association (BE)
Rural Investment Support for Europe (BE)

Project coordinator

Oscar F. Schoumans
Oscar.Schoumans@wur.nl
Wageningen Environmental Research
The Netherlands

Project website: www.systemicproject.eu

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