Cover Delivery Report

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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 ran for four years.

This deliverable contains the factsheets of SYSTEMIC's demonstration plants:

1) *Groot Zevert Vergisting*
2) *Am-Power*
3) *Acqua & Sole*
4) *BENAS*
5) *Waterleau NewEnergy*

SYSTEMIC
Circular solutions for biowaste

Groot Zevert Vergisting (Beltrum, the Netherlands)

A short introduction to GZV

Groot Zevert Vergisting (GZV; Figure 1), located in Beltrum, the Netherlands, started its biogas production in 2004. The plant has a processing capacity of 135 kilotonnes (kt) of feedstock through mesophilic digestion per year. In 2019, GZV started with the production of biobased fertilisers and purified water from digestate. The aim is to offer a sustainable solution for the manure surplus in the region.

Table 1. Technical information of the biogas plant.

Characteristic	
Year of construction	2004
Maximum power output	6.5 MW_e
Digester volume	15 000 m^3
Digestion type	Mesophilic digestion
Nutrient recovery and reuse (NRR) systems	GENIUS: decanter centrifuges, microfiltration, reverse osmosis RePeat: acid leaching of phosphorus and precipitation

Drivers for Nutrient Recycling

In the Netherlands, manure production by livestock exceeds the amount that can be applied on agricultural land within the application rate limits for nitrogen (N) and phosphorus (P). The surplus of manure, about 31% of the produced amount, is exported, mostly to Germany. The transport of large volumes of manure over distances of 200–400 km is costly. Consequently, farmers are faced with high costs for manure disposal (circa €22,- per tonne of pig manure (price level 2021).

Figure 1. Aerial photo of the demonstration plant Groot Zevert Vergisting.

As a solution for the manure surplus in the region, GZV decided to invest in nutrient recovery and reuse (NRR) systems to process digestate into valuable biobased fertilisers:

- Reverse osmosis (RO) concentrate to be used within the region;
- Purified water which is allowed to be discharged in a nearby river;
- Low-P soil improver;
- Precipitated P salts to be used as raw material to produce fertilisers by fertiliser producing companies.

These biobased fertilisers can be used within the region and some of them can be exported over long distances against low costs as their volumes are reduced by processing.

Feedstocks

In 2018, the plant's co-digestion capacity increased from 102 to 135 kt feedstock per year. However, not the entire capacity was used in 2020 (Table 2).

Animal manure was the major substrate (76% of the feedstock mass) but the co-substrates are responsible for circa 77% of the biogas production. Pig manure was collected from about 55 pig farms within a distance of 25 km of the plant.

Table 2. Origin of GVZ's digester feedstock (2020).

Type	Origin	Mass (kt)
Manure	Pig slurry	60
	Dairy cattle slurry	2
	Paunch manure	9
Co-substrates	Residues from agro- and food industry	19
	Glycerine	3
Total		**93**

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Groot Zevert Vergisting (Beltrum, the Netherlands)

Biogas production

In 2020 nearly 10 Mio Nm^3 of biogas were produced (Table 3). About 72% of the produced biogas was transported through a 5 km-long pipeline to a dairy processing factory. The remaining 28% of the produced biogas was on-site converted into electrical energy and heat.

Table 3. Biogas production and average biogas composition before purification for the year 2020.

Parameter	2020
CH_4 (% v/v)	55
CO_2 (% v/v)	43
H_2S (ppm)	1,000–2,000
O_2 (% v/v)	0.2
Total biogas production (Nm^3)	9.7 Mio
Biogas per tonne of feedstock ($Nm^3\,t^{-1}$)	104

Nutrient Recovery and Reuse (NRR) process

The NRR process consist of two independent NRR systems. In the GENIUS system, digestate is first separated into a solid (SF) and a liquid fraction (LF) of digestate by a decanter centrifuge. The SF of digestate is subsequently processed by the RePeat system.

The RePeat system separates the P from the organic matter through leaching with water and sulphuric acid. Two sequential leaching steps remove in total 70–90% of the P present in the ingoing digestate, thereby producing a low-P soil improver. The dissolved P subsequently precipitates through addition of lime ($Ca(OH)_2$) or magnesium hydroxide ($Mg(OH)_2$), thereby producing precipitated P salts. Part of the sulphate, which was added as sulphuric acid, precipitates with calcium as gypsum. The gypsum partly ends up in precipitated P salts and partly in a separated organic gypsum-rich sludge which can be used as fertiliser. Water is continuously reused within the process, thereby preventing the creation of a waste stream.

The LF of digestate is further processed by the rest of the GENIUS system: a second decanter centrifuge, a microfiltration (MF) unit, two RO units placed in series and ion exchangers. The following end products are thereby produced: RO concentrate, rich in N and potassium (K), purified water and a blend of the SF of the second decanter centrifuge and MF concentrate.

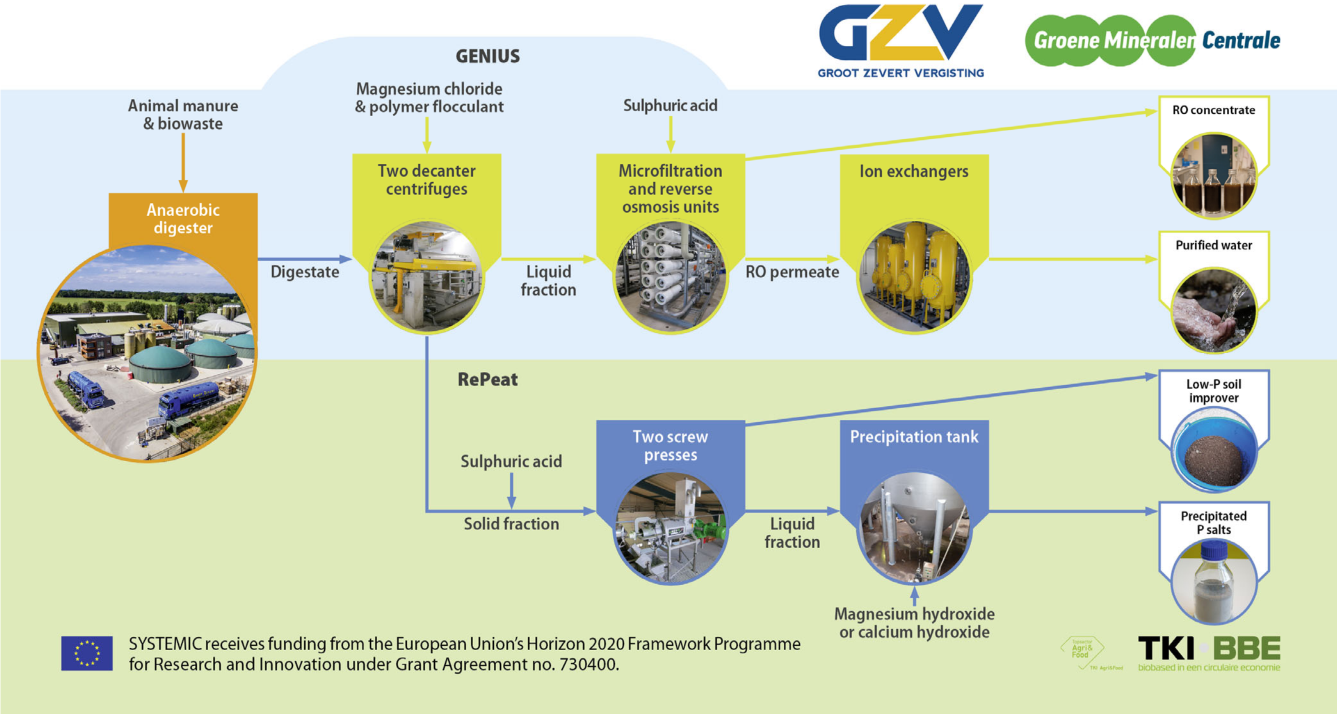

Figure 2. Simplified process flow diagram of Groot Zevert Vergisting's nutrient recovery and reuse systems.

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Horizon 2020

SYSTEMIC
Circular solutions for biowaste

Groot Zevert Vergisting (Beltrum, the Netherlands)

Status of construction

Construction of the RePeat system was finalised in early 2020 and it has since then been used to produce low-P soil improver on demand. It has a processing capacity of two tonnes of SF of digestate per hour. Further improvements to reduce consumption of sulphuric acid and increase the dry matter content of the precipitated P salts are still foreseen. The GENIUS system has been in operation since January 2019. In the years thereafter, GZV and Nijhuis Industries have further improved the achieved separation efficiencies of the system. The performance of both the RePeat and GENIUS systems was monitored by Wageningen Environmental Research.

Products and market

The produced RO concentrate has an average N content of 6.9 g N kg^{-1} of which >90% is NH_4-N , thereby meeting the proposed RENURE criteria. The RO concentrate is blended with other liquid N fertilisers (urea and ammonium sulphate solution) and used as an alternative for synthetic fertilisers on arable land and grass land in the region of the plant. About 20% of the digestate mass is converted into purified water, which can be discharged to surface water. In 2019, the SF of digestate was trucked to Germany. From 2020 onwards it is processed into a low-P soil improver and precipitated P salts. The low-P soil improver is applied on sandy soils in the region of the plant. GZV also investigates its use as an alternative for peat in potting soil and mushroom substrate. The precipitated P salts are yet recovered as a sludge which needs further dewatering and drying after which it can be used as a raw material in the fertiliser industry.

Table 4. Composition of the ingoing digestate and produced end products at Groot Zevert Vergisting (2020 – 2021).

	Digestate	GENIUS			RePeat	
		RO concentrate	Solid fraction of digestate	Purified water	Low-P soil improver	Precipitated P salts[a]
Dry matter (g kg^{-1})	81	37	313	n.a.	284	159
Organic matter (g kg^{-1})	59	14	242	n.a.	252	73
Total N (g kg^{-1})	7.3	8.1	12	0.00028	5.9	6.9
Total P (g kg^{-1})	1.7	0.15	8.9	<0.0001	1.9	8.8
Total K (g kg^{-1})	4.5	7.9	4.6	<0.0004	1.8	2.3
Total S (g kg^{-1})	0.67	1.5	1.9	0.0029	5.8	12

[a] Precipitated phosphorous salts before further dewatering and drying.

Economic benefits

Long distance transport of digestate or SF of digestate to Germany is costly. Implementation of the GENIUS and RePeat systems has enabled GZV to dispose of their products to farmers in the region of the plant and to discharge part of the digestate mass, in the form of purified water, to surface water. Thereby GZV saves on costs for transport.

Sustainability goals

GZV is committed to reaching the following targets:

- Production of biogas from animal manure and residues from the agro- and food industry and offering a sustainable disposal solution for the surplus of animal manure in the region.
- Reduction of long-distance transport of digestate and its end products.
- Replacement of synthetic N fertiliser by a biobased mineral fertiliser blend, containing 10–15 g L^{-1} N-NH_4 and 10–15 g L^{-1} K_2O, made from the RO concentrate.
- Replacement of peat in potting soil or in substrate for the growing of mushrooms by the low-P soil improver.

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 ran for four years.

Horizon 2020

Monitoring data: total mass flows

Total mass (Figure 3) flows were calculated for the GENIUS system of GZV for the period September 2020 – February 2021. This was done to evaluate the overall performance of the plant and the separation efficiencies of the individual process units. $MgCl_2$ was added to the ingoing digestate to improve separation of P by the first decanter centrifuge. The first decanter centrifuge separated 63% of the ingoing P to the SF of digestate. Together, the first and second decanter centrifuge removed 88% of the P from the ingoing digestate. The MF unit removed 86% of the remaining P as well as 90% of the remaining organic N. This however resulted in a large volume of MF concentrate, a sludge, that was disposed of mixed with the SF of the second decanter centrifuge. The MF permeate was concentrated by a factor 2.0 by the two subsequent RO units placed in series. Half of the produced purified water was reused within the process. Every tonne of ingoing digestate resulted in 15 kg of SF of digestate, 35 kg of sludge (trucked off-site), 31 kg of RO concentrate and 18 kg of discharged/evaporated purified water. Water production was lower than envisaged and production of sludge was larger than envisaged.

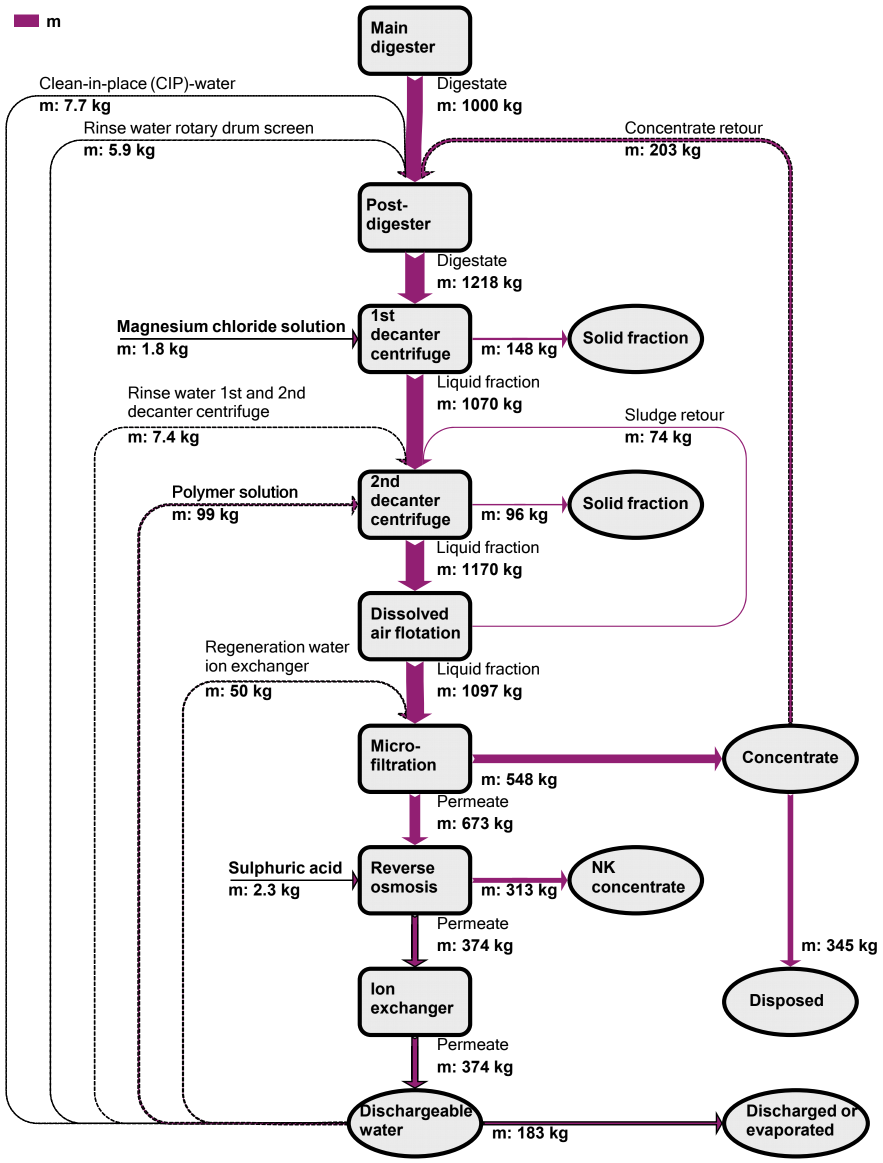

Figure 3 Total mass (m) flows of the GENIUS system at Groot Zevert Vergisting in kg per 1000 kg of processed digestate.

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Horizon 2020

Groot Zevert Vergisting (Beltrum, the Netherlands)

Monitoring data: total mass flows

Total mass (Figure 4) flows were calculated for the RePeat system of GZV for the period September 2020 – July 2021. Of the P in the ingoing SF of digestate, 70% ended up in the precipitated P salts and respectively only 16% and 14% in the low-P soil improver and the sludge of the lamella clarifier. Every tonne of ingoing SF of digestate resulted in 970 kg of low-P soil improver, 512 kg of sludge (trucked off-site) and 793 kg of precipitated P salts due to addition of RO permeate. The DM content of the precipitated P salts is 18% which is lower than envisaged. The sludge of the lamella clarifier is a by-product consisting of fine organic matter. The sludge volume needs to be reduced to increase the economic profits. Overall, P separation efficiency of the RePeat system was as envisaged. Further optimization is needed to decrease the volume of sludge and precipitated P salts. GZV investigates possibilities to sell the low-P soil improver as an alternative for peat in potting soil or in substrate for the growing of mushrooms.

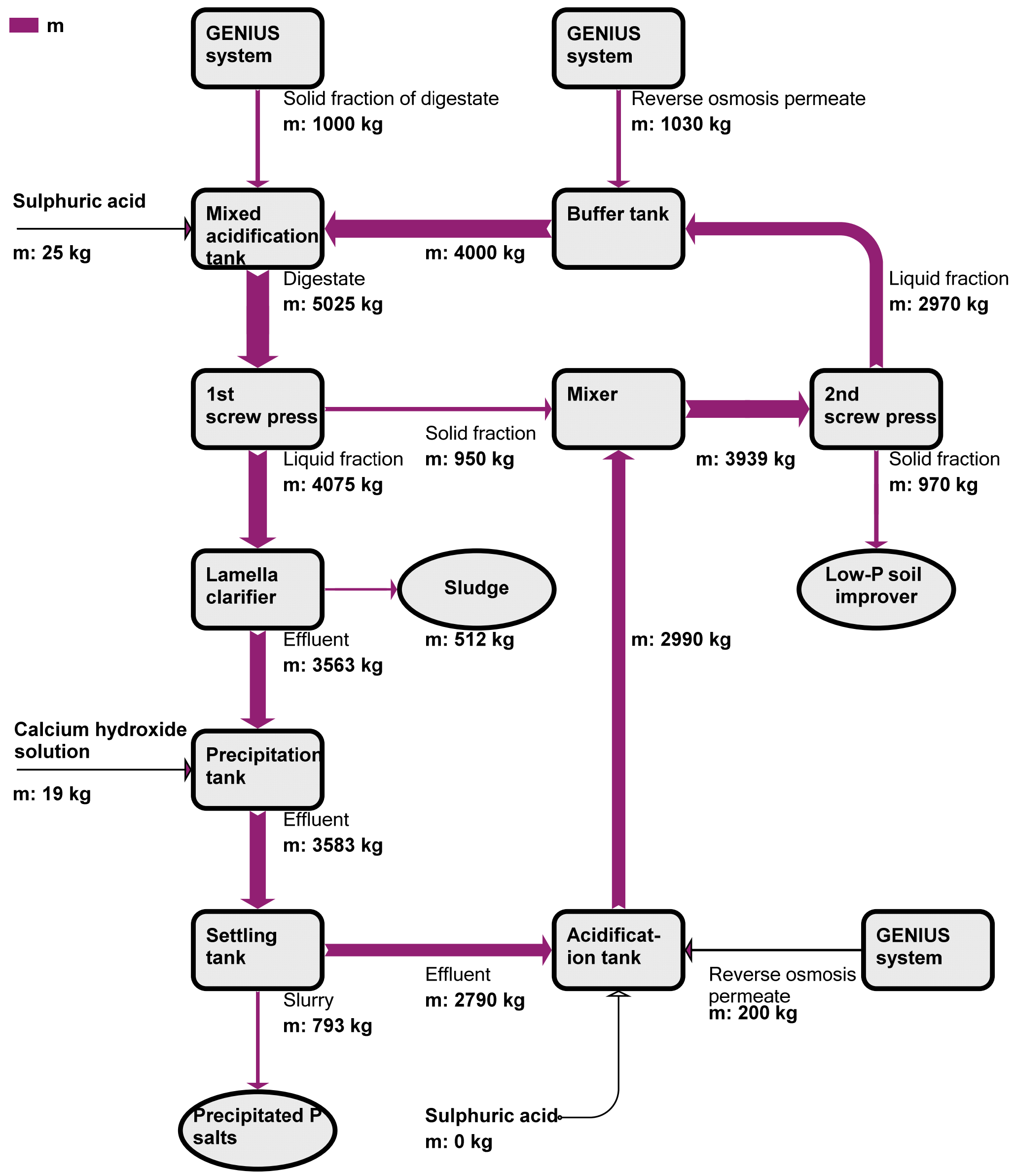

Figure 4 Total mass (m) flows of the RePeat system at Groot Zevert Vergisting in kg per 1000 kg of processed solid fraction of digestate.

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Horizon 2020

SYSTEMIC
Circular solutions for biowaste

Groot Zevert Vergisting, Beltrum (the Netherlands)

Monitoring data: energy balance

In 2020 the plant produced 47,837 MWh energy in the form of biogas (Figure 5) of which 72% was sold to a nearby dairy processing factory via a 5-km long pipeline. The majority of the remaining biogas was converted into 5,597 MWh electrical energy and 3,623 MWh of usable thermal energy by the combined heat and power (CHP) installation. Of this electrical energy 32% was sold via the grid and 68% was used on-site for the anaerobic digestion (AD) plant and the NRR systems GENIUS and RePeat. The thermal energy was used on-site for heating of the digesters and buildings and for hygienisation of the digestate in the post-digester.

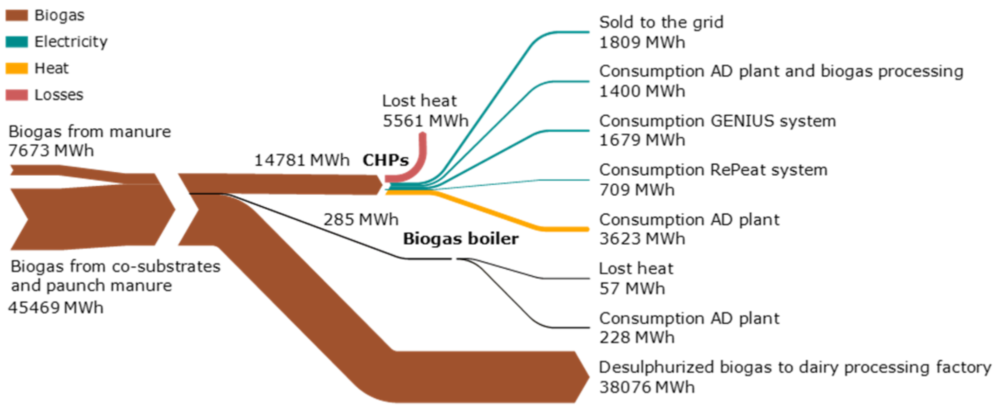

Figure 5 Energy balance of the anaerobic digestion (AD) and nutrient recovery and reuse systems at Groot Zevert Vergisting for the year 2020.

Key Performance Indicators (KPIs)

Economic KPIs are simple tools to gain insight into a company's economic performance:

KPI_1: EBIT (Earnings Before Interest and Taxes) margin as % of revenues.
KPI_2: EBITA (Earnings Before, Interest, Taxes and Amortisation) margin as % of revenues.
KPI_3: Substrate (financial) productivity → total gross revenues per tonne of feedstock.
KPI_4: Biogas (financial) productivity → net revenues of biogas (energy / green certificates) per cubic meter of biogas delivered.
KPI_5: Digestate (financial) productivity → net costs/revenues generated by digestate per tonne of feedstock.

Table 7. Economic KPIs of Groot Zevert Vergistings's plant.

KPI	
EBIT margin	12%
EBITA margin	49%
Substrate productivity	€34.52 / tonne feedstock
Biogas productivity	€0.32 / Nm^3 biogas
Digestate productivity	€-3.63 / tonne feedstock

Compared to the other SYSTEMIC demonstration plants, GZV has a relatively high biogas financial productivity. Processing and disposal of digestate is still costly because GZV does not generate revenues from all produced biobased fertilisers yet. Still, digestate financial productivity is higher than for most of the other SYSTEMIC demonstration plants. The produced RO concentrate is blended into Green Meadow Fertiliser (GWM). The farmer to whom the GWM is delivered pays for the amount of N he or she receives. From these revenues GZV pays the storage, transport and field application of the GWM on the farmer's land.

More information on the economic KPI analysis is available in deliverable D2.4: *'Final report on the development and application of economic key performance indicators (KPIs)'.*

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Horizon 2020

Am-Power (Pittem, Belgium)

A short introduction to Am-Power

Am-Power (Figure 1) is located in the western part of Flanders (Belgium), a region with a surplus of animal manure and a high market demand for synthetic fertiliser. This SYSTEMIC demonstration plant is the largest biogas plant in Belgium: it has a processing capacity of 180 kilotonne (kt) feedstock per year, spread over four digesters and one post-digester.

Table 1. Technical information of the biogas plant.

Characteristic	
Year of construction	2011
Maximum power output	7.5 MW_e
Digester volume	20 000 m^3
Digestion type	Thermophilic digestion

Drivers for nutrient recycling

Am-Power has a history of experimenting with and investing in nutrient recovery innovations. Several years ago, Am-Power already envisaged the importance and benefits of moving towards a circular economy because disposal of the digestate is an important part of the costs for biowaste processing plants. On top of this, the agro food industry in Flanders realises that their waste streams are valuable and thus demand a gate fee to biogas plants for intake of their biowaste.

Figure 1. Aerial photo of the demonstration plant Am-Power.

Competition between biogas plants makes it difficult to achieve a cash flow above the breakeven point. Am-Power believes that nutrient recovery can be a way to achieve this. Am-Power produces about 160 kt of digestate per year and strives to process it in a cost effective, efficient and relatively simple way, without losing the nutrients. The plant has developed and implemented a process for the recovery of nutrients in the form of valuable fertilisers which is currently being optimised.

Feedstock

In 2020, the co-digestion plant processed 153 kt feedstock of which more than 52% was organic biological waste (industrial food waste and source-segregated food waste (SSFW)). Co-substrates mainly include animal manure and glycerine (Table 2). Organic biological waste and animal manure are processed in separate digestion lines (digester 1 and 2).

Table 2. Origin of Am-Power's digester feedstock (2020).

Type	Mass (kt)
Digester 1 (non-manure)	
Food waste & SSFW	**80**
Food industry sludge	**21**
Glycerine and fatty substrates	**15**
Others	**15**
Digester 2 (manure)	
Manure (slurry)	**19**
Solid fraction of manure	**2.4**
Total	**153**

Anaerobic digestion (AD)

- Organic waste is collected and homogenised in a mixer to a substance with a dry matter (DM) content of approximately 20%.
- Homogenised feedstock is hydrolysed in a separate tank (with a retention time of 3 days) and fed to a thermophilic digester.
- Retention time in the digester is about 50–60 days and about 10 days in the post-digester.

Horizon 2020

Am-Power (Pittem, Belgium)

Biogas production

In 2020, around 15 million m³ biogas was produced, digesters and post-digester included (Table 3). The biogas is converted by a Combined Heat and Power (CHP) installation into thermal and electrical energy. The calculated amounts of heat and electricity produced in 2020 are respectively 32,166 MWh_{th} and 29,727 MWh_e.

Table 3. Biogas production and average biogas composition before purification for the year 2020).

Parameter	Amount
CH_4 (% v/v)	57
CO_2 (% v/v)	44
Total biogas production (Nm³)	15 Mio
Biogas per tonne of feedstock (Nm³ t^{-1})	95

Nutrient Recovery & Reuse (NRR) process

The previous process worked as follows:

- Digestate was diluted with liquid fraction (LF) of digestate and sent to two decanter centrifuges for solid-liquid separation. Coagulation and flocculation were favoured by the addition of respectively iron sulphate and polymer flocculant. Dilution with recirculated LF of digestate was necessary to achieve a better efficiency of the reverse osmosis (RO) step. Each of the two decanter centrifuges require about 146 kW of electric power.
- The phosphorus (P) rich solid fraction (SF) of digestate, with a DM content of 24%, was dried in a fluidised bed dryer (requiring 268 kW_e and 3000 kW_{th}) with waste heat from the CHP installation. To do so, exhaust gas from the CHP installation (160 °C) is mixed with ambient air to a temperature of 80 °C. The dried SF of digestate (with a total P and DM content of respectively 2% and 90%) were exported to France where there is demand for P.
- The LF of digestate, rich in nitrogen (N) and potassium (K), was first processed in a dissolved air flotation (DAF) unit. Iron chloride and polymer flocculant were added to reduce the DM content of the LF to 1.2–1.6%. The subsequent RO unit required the addition of sulphuric acid to the influent to ensure a good membrane separation. The resulting RO concentrate, rich in N and K (respectively 0.5% and 0.4%), was used as a fertiliser on local agricultural land. RO permeate water was reused on-site.

The adjusted process includes a continuous vacuum evaporator prior to the RO unit, thereby increasing the recovery of nutrients from digestate (Figure 2).

- The decanter centrifuge, with addition of polymer flocculant to improve separation, separates the digestate in an SF and an LF of digestate.
- As in the previous process, the SF of digestate (25–30% DM) is dried up to 80–90% DM.
- The LF of digestate (3.5–4.5% DM) flows into an acidification tank where addition of sulphuric acid lowers the pH to 6.5–7 to prevent ammonia losses in the subsequent evaporation step. Compared to the previous NRR system, the amount of polymer flocculant needed decreased from 63 to 38 tonnes per year.
- The vapour produced by the vacuum evaporator, containing <0.1% mineral N, is condensed to form condensed water. Currently, the condensed water is reused to a.o. dilute the digester feedstock, make the polymer flocculant solution or clean the evaporator plates. In the future, the RO unit (57 kW_e) will process it into dischargeable purified water.
- The evaporator concentrate, which has a DM content >10%, will be blended with the dried SF of digestate into an organic NPK fertiliser and applied on agricultural land. Each of the two evaporator units require about 381 kW_e and 1500 kW_{th}, which is a lot more than the DAF unit did require.

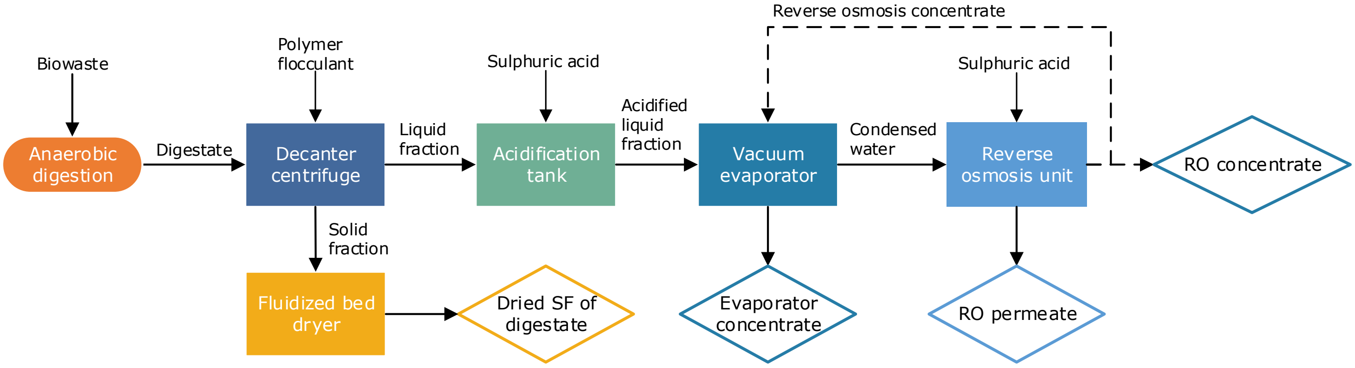

Figure 2. Simplified process flow diagram of Am-Power's current nutrient recovery and reuse system.

Am-Power (Pittem, Belgium)

Status of construction

The vacuum evaporator consists of two identical units, each with an evaporation capacity of 150 m^3 d^{-1}. Both units have been installed and are operational (Figure 3). Since the total N content of the permeate water (108 mg L^{-1}) did not comply with Flemish discharge limits (15 mg L^{-1}), Am-Power has installed an acidification step prior to the evaporator to reduce lower the amount of ammonia that evaporates. This results in a higher total N content of the evaporator concentrate. The investment costs for the evaporator and adaptation costs of the process amounted to € 2 million in total.

Figure 3. Photo of the vacuum evaporator.

The new RO unit however suffers from continuous membrane fouling, Am-Power is currently adjusting several process steps to overcome this issue.

Products and market

- The digestate previously processed with the DAF unit and RO unit resulted in a dried P-rich SF of digestate and an RO concentrate. The RO concentrate was applied on agricultural land in the region, whereas the dried SF of digestate was exported to France.
- With the current process, Am-Power will blend part of the evaporator concentrate and the dried SF of digestate (ratio 1:1) into an NPK fertiliser to be exported to regions with demand for this fertiliser, such as France. Product characteristics are given in Table 4.

Table 4. Composition of the ingoing digestate and produced end products at AM-Power (October 2020 – April 2021).

	Digestate	Liquid fraction of digestate	Evaporator concentrate	Dried solid fraction of digestate
pH	8.1	8.3	6.2	8.1
Dry matter (g kg^{-1})	81	26	115	823
Organic matter (g kg^{-1})	50	14	63	529
Total N (g kg^{-1})	4.9	4.0	7.1	23
NH_4-N (g kg^{-1})	2.3	2.4	3.0	1.3
Total P (g kg^{-1})	1.4	0.21	2.2	19
Total K (g kg^{-1})	3.3	3.1	5.6	14

Economic benefits

The economic advantages of the produced end products are:

- Monitoring of Am-Power suggests that up to 75% of the water in the LF of digestate is removed in the vacuum evaporator and will, after future polishing by an RO unit, become available as dischargeable purified water. An additional 45 m^3 of water per day is removed by drying the SF of digestate. These amounts of water do not have to be transported.
- Replacement of the DAF unit by the vacuum evaporator cuts costs for chemical additives.

Sustainability goals

Am-Power is committed to reaching the following targets:

- Reducing CO_2 emissions related to digestate transport.
- Reducing the addition of polymer flocculant and eliminate the addition of iron salts.
- Increasing the production of permeate water.

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Horizon 2020

Monitoring data: total mass and nutrient mass flows

Total mass (Figure 4) and nutrient mass (Figure 5) flows were calculated for the NRR system of Am-Power for the period October 2020 – April 2021. This was done to evaluate the overall performance of the plant and the separation efficiencies of the individual process units.

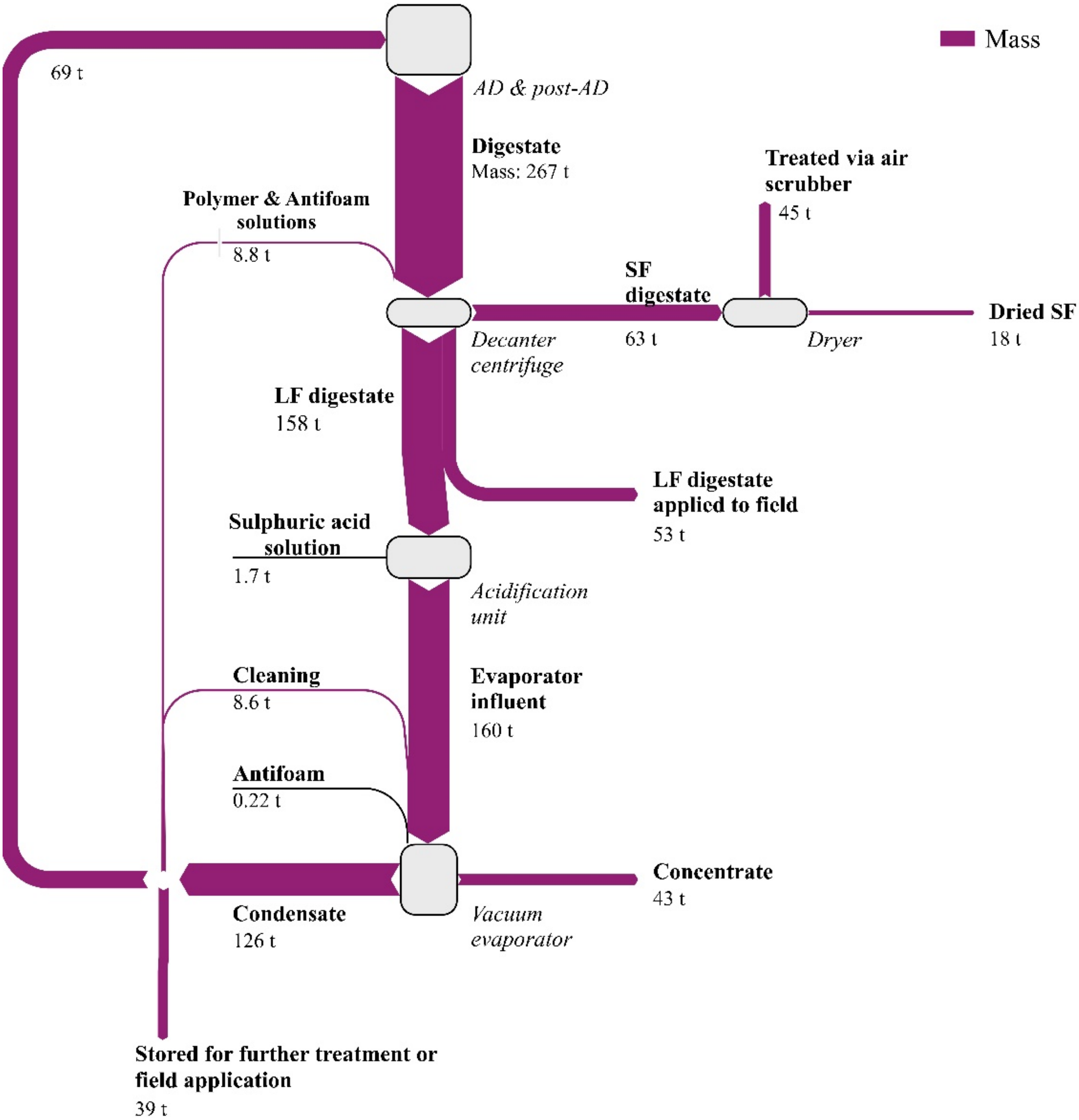

Figure 4. Total mass flows of the nutrient recovery and reuse system at Am-Power in tonnes (t) per day.

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Horizon 2020

Am-Power (Pittem, Belgium)

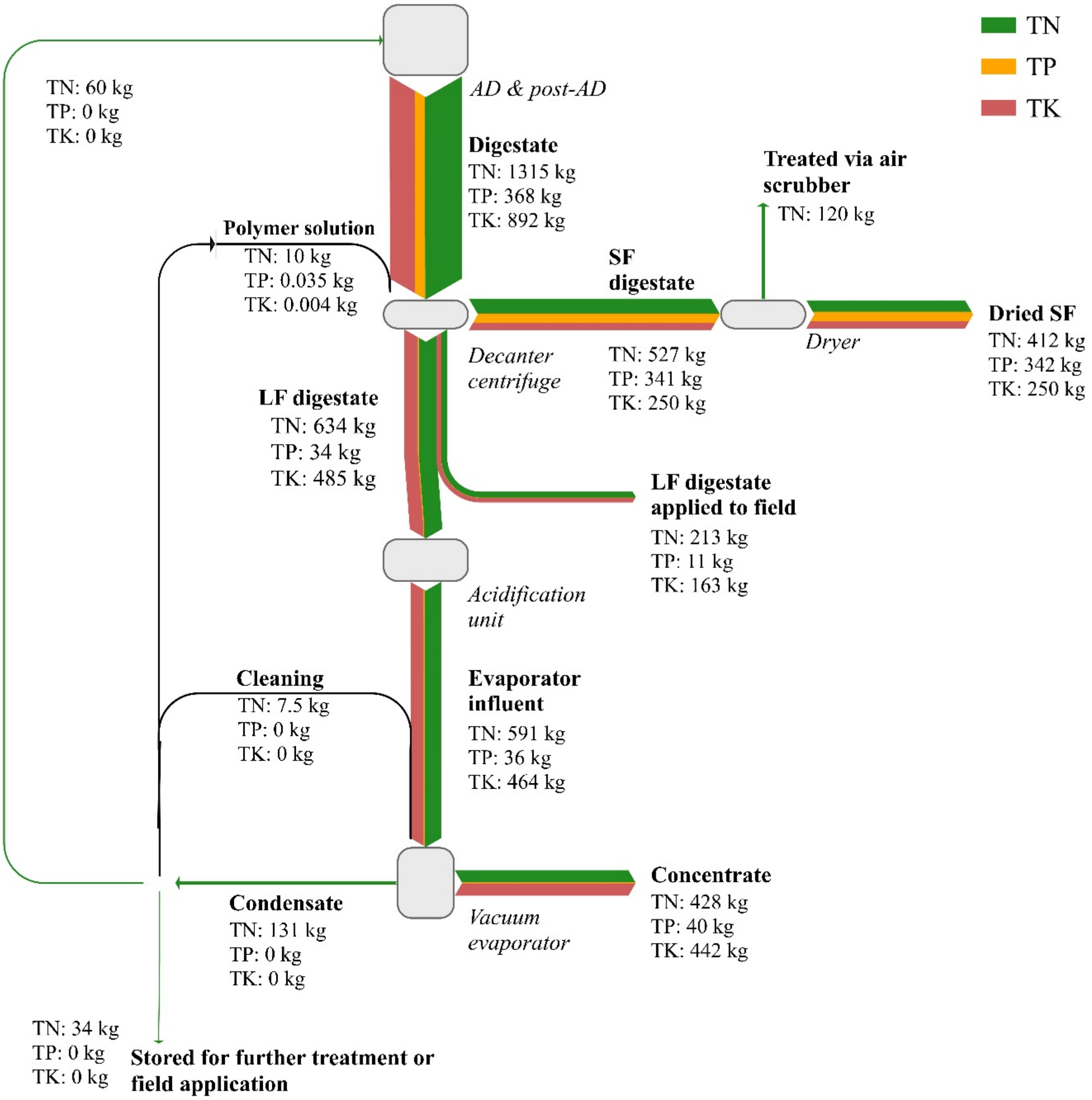

Figure 5. Total nitrogen (TN), total phosphorus (TP) and total potassium (TK) mass flows of the nutrient recovery and reuse system at Am-Power in kilogram (kg) per day.

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Horizon 2020

Am-Power (Pittem, Belgium)

Monitoring data: energy balance

In 2020 the plant generated 29,727 MWh of thermal energy. The CHP installation also generated 32,166 MWh of electricity, of which 13% was in total consumed by the AD and NRR system. The remainder was sold via the national grid (Figure 6).

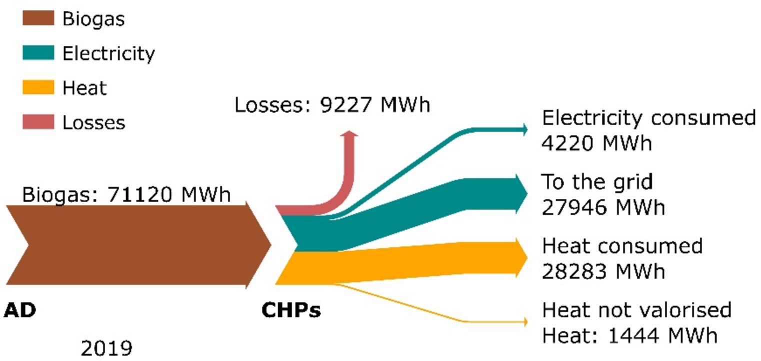

Figure 6. Energy balance of the anaerobic digestion and nutrient recovery and reuse system at Am-Power for the year 2020.

Key Performance Indicators (KPIs)

Economic KPIs are simple tools to gain insight into a company's economic performance:

KPI_1: EBIT (Earnings Before Interest and Taxes) margin as % of revenues.
KPI_2: EBITA (Earnings Before Interest, Taxes and Amortisation) margin as % of revenues.
KPI_3: Substrate (financial) productivity → total gross revenues per tonne of feedstock.
KPI_4: Biogas (financial) productivity → net revenues of biogas (energy / green certificates) per cubic meter of biogas delivered.
KPI_5: Digestate (financial) productivity → net costs/revenues generated by digestate per tonne of feedstock.

Table 7. Economic KPIs of Am-Power's plant.

KPI	
EBIT margin	3%
EBITA margin	25%
Substrate productivity	€44 / tonne feedstock
Biogas productivity	€0.24 / Nm^3 biogas
Digestate productivity	€-7.2 / tonne feedstock

Despite the large scale of the plant, Am-Power deals with high costs for feedstock, which translates into a low substrate financial productivity.
Although the digestate financial productivity is negative, the implementation of the NRR system for processing of the digestate increased the digestate financial productivity from € -17 per tonne of feedstock to €-7.25 per tonne of feedstock.

More information on the economic KPI analysis is available in deliverable D2.4: *'Final report on the development and application of economic key performance indicators (KPIs)'.*

Acqua & Sole (Vellezzo Bellini, Italy)

A short introduction to Acqua & Sole

The biogas plant of Acqua & Sole (Figure 1) is located in Vellezzo Bellini (Northern Italy), in an area dedicated to cereal cultivation, mainly rice. This SYSTEMIC demonstration plant focusses on nutrient recycling, specifically development of equipment for digestate application to agricultural land (direct injection into the soil). This equipment is developed in collaboration with local farmers.

Table 1. Technical information of the biogas plant.

Characteristics	
Year of construction	2016
Maximum power output	1.6 (MW_e)
Digester volume	13 500 (m^3)
Digestion type	Thermophilic digestion

The aim for development of this equipment was to improve fertilisation and reduce ammonia (NH_3) and odour emissions. In addition to the production of a soil improver (digestate), the plant produces ammonium sulphate solution from recovered ammoniacal nitrogen (NH_4-N) by N-stripping of the digestate during anaerobic digestion (AD). This ammonium sulphate solution is used as N fertiliser. For the recovery and reuse of nutrients, Acqua & Sole has the ambition of improving the soil fertility of an area of 5,000 hectares without using any synthetic fertilisers. Acqua & Sole also wants to deliver recovered nutrients to surrounding farms.

Drivers for nutrient recycling

Degradation of N-rich digester feedstock leads to the formation of NH_3 which can have an inhibiting effect on anaerobic methanogenic microorganisms when toxic NH_3 levels are reached. Stripping of NH_3 and its subsequent recovery as ammonium sulphate solution is a great opportunity to prevent inhibition of the AD process. Furthermore, the low carbon contents of soils is an issue in Italy and the utilisation of soil improvers (i.e. digestate) is a valuable means to tackle this. However, N application rate limits for agricultural land limit the use of organic materials, making it necessary to find solutions to lower the N content of the produced digestate.

Figure 1. Aerial photo of the demonstration plant Acqua & Sole.

Feedstocks

The plant's co-digestion capacity is 120 kilotonnes (kt) organic feedstock per year. In 2020, about 88 kt of feedstock were digested of which roughly 84% was sewage sludge and roughly 16% was digestate from anaerobic treatment of source-segregated domestic food waste (SSFW) and agro-food waste (Table 2). The plant can digest animal manure, expired food, organic wastes, sewage sludge and agro-food industry waste.

Table 2. Origin of Acqua & Sole's digester feedstock (2020).

Type	Origin	Mass (kt)
Sewage sludge	Wastewater treatment plants	74
Co-substrates	Digestate from anaerobic treatment of source-segregated domestic food waste	4.5
	Agro-food waste	9.0
Total		**87.5**

Horizon 2020

Acqua & Sole (Vellezzo Bellini, Italy)

Biogas production

AD is performed in three consecutive digesters with a volume of 4,500 m^3 each. The produced biogas (Table 3) is converted into electrical anergy and thermal energy by a Combined Heat and Power (CHP) installation. From March 2020 onwards, part of the biogas is also fed to a back-up biogas boiler to meet the plant's heat demand, thereby avoiding the use of natural gas.

Table 3. Biogas production and average biogas composition before purification for the year 2020.

Parameter	Amount
CH_4 (% v/v)	60–67
CO_2 (% v/v)	32–36
H_2S (ppm)	<10
O_2 (% v/v)	<1
Total biogas production (Nm^3)	3.3 Mio
Biogas per tonne of feedstock (Nm^3 t^{-1})	38

Digestate characteristics

- Thermophilic digestion ensures a better control of pathogenic and intestinal microorganisms in the digestate.
- The high total N/NH_4-N ratio of the digestate favours long-term fertilisation.
- Homogeneous field distribution of the digestate is ensured by the digestate injection application equipment (Figure 2).

Figure 2. Digestate injection application on agricultural land.

Nutrient Recovery and Reuse (NRR) process

From April 2016 onwards, the plant has operated as follows (Figure 3):

- Feedstock (organic waste) is collected in basins located in a closed building to prevent the release of odour. A biofilter placed on the roof of the building purifies the exhausted air;
- The organic waste is then heated and mixed with digestate from the third digester;
- The mixed feedstock then undergoes thermophilic AD (minimum retention time of 20 days at a temperature of 55 °C) which ensures hygienisation of the ingoing sewage sludge;
- The system of digesters is equipped with a side-stream N-stripper, in which NH_3 is stripped from the stripping agent, biogas. This is done by leading biogas through 50% sulphuric acid resulting in an ammonium sulphate solution.
- For the previous absorption unit biogas was used as stripping agent. For the new N-scrubber, biogas has been replaced by air. Moreover, the novel N-absorber is made of the high-performance material Alloy 825, which allows higher process temperatures.
- The novel absorber design enables a higher gas flow rate, thereby increasing the recovery of NH_4-N from the digestate entering the N-stripper to up to 35%. With the previous absorption unit an NH_4-N recovery of just about 20% was achieved.
- Both the digestate and the ammonium sulphate solution are stored in close tanks.

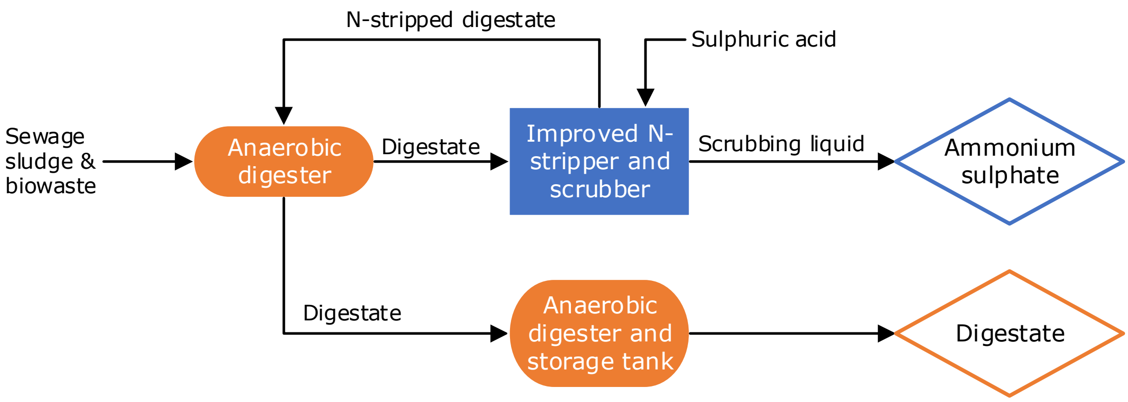

Figure 3. Simplified process flow diagram of Acqua & Sole's current nutrient recovery and reuse system..

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 ran for four years.

Horizon 2020

Acqua & Sole (Vellezzo Bellini, Italy)

Status of construction

Construction of the novel N-absorber started in March 2019 and was completed at the end of 2019. For the start up of the new absorption unit the existing unit had to be switched of. This transitional period had to be as short as possible to avoid NH_3 inhibition of the digesters and took place in January 2020. Currently, the whole system is finalised and fully operational.

Products and market

The plant's co-digestion capacity is 120 kt organic feedstock per year. This feedstock is mixed with water and processed into at maximum 192 kt of N-stripped digestate per year. The composition of the produced end products is given in Table 4.
Acqua & Sole estimated that the use of N-stripped digestate replaces the following amounts of synthetic fertilisers per year: 1550 t N, 1160 t P_2O_5 and 170 t K_2O.

Table 4. Composition of the produced end products at Acqua & Sole (October 2020 – April 2021).

	N-stripped digestate	Ammonium sulphate solution
Dry matter (g kg^{-1})	106	360
Organic matter (g kg^{-1})	63	-
Total N (g kg^{-1})	8.0	75
Total P (g kg^{-1})	3.4	0.012
Total K (g kg^{-1})	0.59	0.017
Total S (g kg^{-1})	1.1	85

Economic benefits

There are no revenues to Acqua & Sole from the N-stripped digestate. Acqua & Sole however calculated that the replacement of conventional fertiliser with N-stripped digestate for 5,000 hectares agricultural land saves them about €2.3 million on conventional fertilisers per year (Table 5). The implemented novel N-absorber further reduces the N content of the N-stripped digestate. Therefore, even more of it can be applied per hectare on their own fields.

Table 5. Saved costs by application of N-stripped digestate.

Conventional fertiliser	Price (€ t^{-1})*	Quantity (t y^{-1})	Total costs (€)
Urea 46% N	344	3 370	1 159 280
Triple superphosphate 46% P_2O_5	369	2 520	929 880
Potash 60% K_2O	669	280	187 320
Total saved costs			**2 276 480**

** Source: CCIAA Modena, average for the year 2017.*

This results in lower costs for transport and disposal. The further reduced NH_3 concentration in the digesters optimises the digestion process, by avoiding NH_3 inhibition of the microorganisms. Also, it increases the production of ammonium sulphate solution.

Sustainability goals

Acqua & Sole is committed to reaching the following targets:

- Closing nutrient cycles through the use of fertilisers produced from sewage sludge and biowaste;
- Showcasing that fertilisers produced from sewage sludge and biowaste are agronomically effective and environmentally friendly;
- Increasing soil quality, via carbon sequestration, due to the field application of digestate instead of conventional fertilisers;
- Reducing emissions of NH_3 and N_2O during field application of digestate;
- Reducing emissions of unpleasant odours during field application of digestate to improve public acceptance for their end products.
- Production of a highly stabile digestate and its field application via injection to improve its public acceptance. This is possible due to the absence of unpleasant odours during application.

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 ran for four years.

Horizon 2020

Monitoring data: total mass and nutrient mass flows

Total mass (Figure 4) and nutrient mass (Figure 5) flows were calculated for the plant for the period October 2020 – April 2021, 189 days in total. The calculated total amount of total N in the end products was 14% larger than the amount of total N in the feedstock, making calculation of the NH_4-N recovery efficiency difficult. A recent other study showed that the novel scrubber of Aqua&Sole can achieve NH_4-N recovery efficiencies of up to 35% (Di Capua *et al.*, 2021) relative to N-NH_4 in the feed of the stripper. As the stripper is operated on a side stream of the AD plant, overall N separation efficiency was lower (about 8% as compared to TN) which is sufficient to control N-NH_4 levels in the digester.

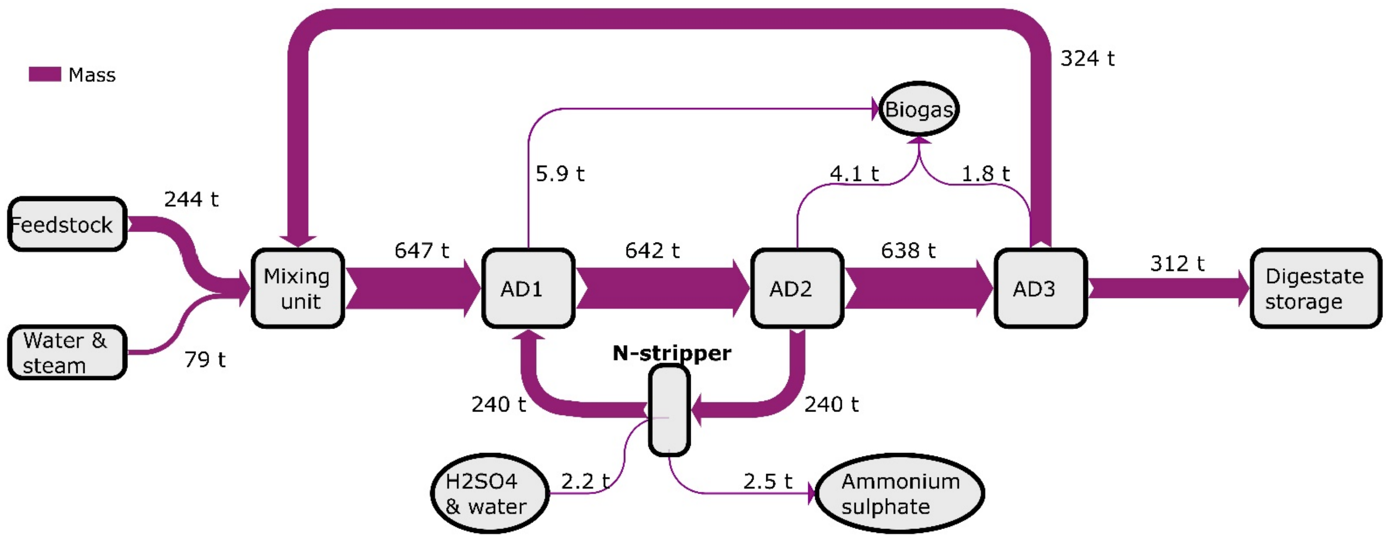

Figure 4. Total mass flows of the nutrient recovery and reuse system at Acqua & Sole in tonnes (t) per day.

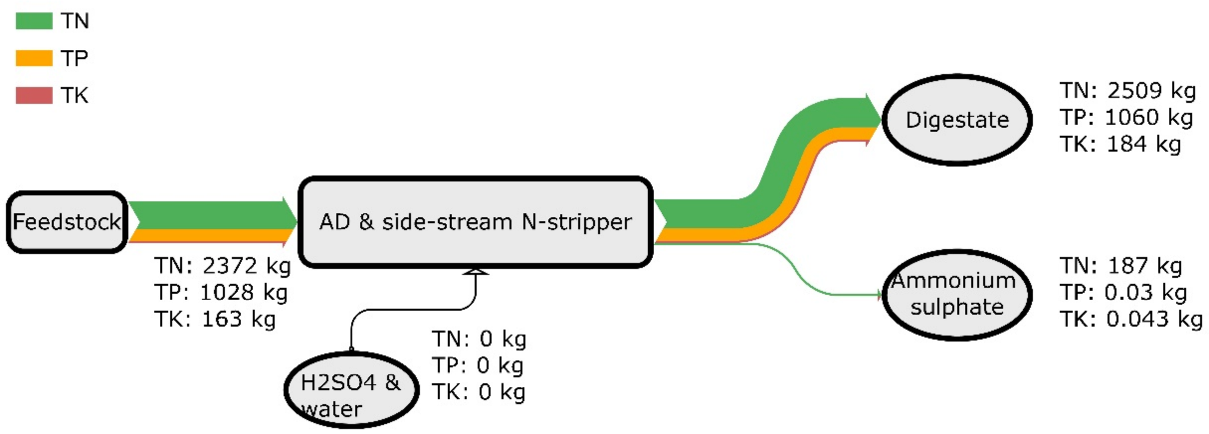

Figure 5. Total nitrogen (TN), total phosphorus (TP) and total potassium (TK) mass flows of the nutrient recovery and reuse system at Acqua & Sole in kilogram (kg) per day.

Di Capua, F., Adani, F., Pirozzi, F., Esposito, G., & Giordano, A. (2021). Air side-stream ammonia stripping in a thin film evaporator coupled to high-solid anaerobic digestion of sewage sludge: Process performance and interactions. Journal of Environmental Management, 295, 113075.

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 ran for four years.

Horizon 2020

Acqua & Sole (Vellezzo Bellini, Italy)

Monitoring data: energy balance

Over the period October 2020 – April 2021 the plant generated 5,348 MWh of thermal energy, of which 5,103 MWh from biogas in the CHP installation. The remaining 245 MWh of thermal energy were produced from natural gas in the back-up boiler. This was needed as the biogas boiler, which is normally used, was not in operation for one month due to a technical issue. The CHP installation also generated 3,820 MWh of electricity, of which about 4% was consumed by the N-stripper (Figure 6).

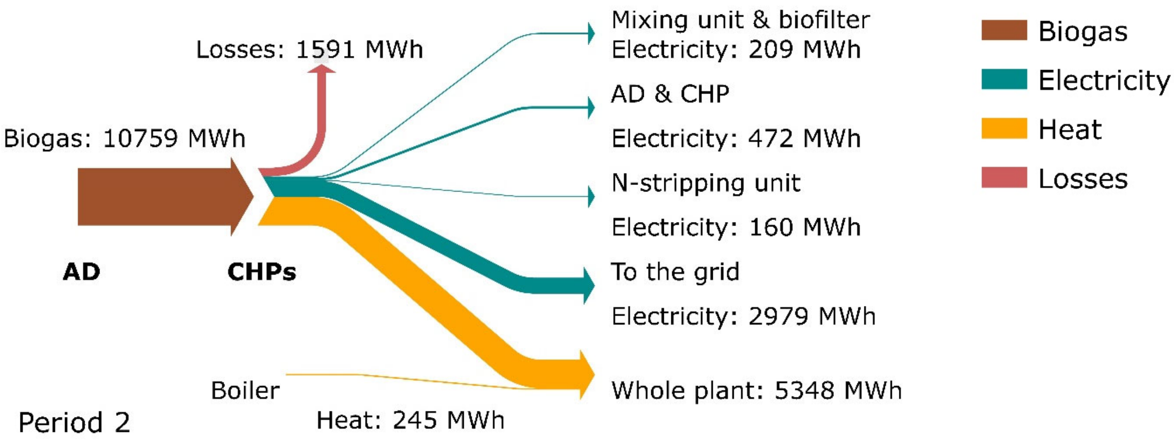

Figure 6. Energy balance of the anaerobic digestion (AD) and nutrient recovery and reuse system at Acqua & Sole for the period October 2020 – April 2021. CHPs: electrical and thermal energy generated by the CHPs includes thermal energy generated by the biogas boiler. Boiler: back-up boiler on natural gas.

Key Performance Indicators (KPIs)

Economic KPIs are simple tools to gain insight into a company's economic performance:

KPI_1: EBIT (Earnings Before Interest and Taxes) margin as % of revenues.
KPI_2: EBITA (Earnings Before, Interest, Taxes and Amortisation) margin as % of revenues.
KPI_3: Substrate (financial) productivity → total gross revenues per tonne of feedstock.
KPI_4: Biogas (financial) productivity → net revenues of biogas (energy / green certificates) per cubic meter of biogas delivered.
KPI_5: Digestate (financial) productivity → net costs/revenues generated by digestate per tonne of feedstock.

Table 7. Economic KPIs of Acqua & Sole's plant.

KPI	
EBIT margin	16%
EBITA margin	41%
Substrate productivity	€57 / tonne feedstock
Biogas productivity	€0.34 / Nm^3 biogas
Digestate productivity	€-4.6 / tonne feedstock

The plant has an average substrate financial productivity compared to the other SYSTEMIC demonstration plants. Even though the produced electricity is sold at market price, without any targeted support schemes, the plant's biogas financial productivity is still average compared to the other SYSTEMIC demonstration plants.

More information on the economic KPI analysis is available in deliverable D2.4: '*Final report on the development and application of economic key performance indicators (KPIs)*'.

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 ran for four years.

Horizon 2020

Factsheet
SYSTEMIC demonstration plant

BENAS (Ottersberg, Germany)

A short introduction to BENAS

The SYSTEMIC demonstration plant of BENAS (Figure 1) is located in the north of Germany, near Bremen. The plant has a processing capacity of 174 kilotonnes (kt) feedstock per year divided over four digesters and three storage tanks. BENAS also owns 3,500 hectares of arable land (1,000 ha near Ottersberg), has 35 employees and its own truck fleet.

Table 1. Technical information of the biogas plant.

Characteristic	
Year of construction	2006
Maximum power output	11.3 MW_e
Digester volume	39 100 m^3
Digestion type	Thermophilic digestion

Drivers for nutrient recycling

Chicken manure is readily available in the region as a feedstock for biogas plants at a relatively low price to be paid to the farmer. However, due to ammonia (NH_3) inhibition of the anaerobic microorganism, it is a difficult feedstock to digest. Restrictions on nitrogen (N) application on agricultural land make its disposal difficult. This leads to high transportation cost due to large transport distances.

Figure 1. Aerial photo of the demonstration plant BENAS.

BENAS has been forced to search for a digestate processing technology that lowers the NH_3 content of the digestate, recovers N and reduces the amount of digestate for field application. The plant director owns arable land, 200 km from Ottersberg, which is fertilised with fertilisers produced by BENAS from digestate. Trucks bring the fertilisers to the arable land and drive back to Ottersberg with energy crops that are used as feedstock for the digester. BENAS benefits from the investments in nutrient recovery and reuse technologies: higher biogas production and a larger feedstock share of chicken manure due to NH_3 stripping, lower stripping costs due to the use of gypsum instead of acids for scrubbing of NH_3 and revenues from selling the produced low-N fibres.

Feedstocks

The co-digestion capacity is 174 kt feedstock (organic substrate) per year. In 2019, the plant digested about 92 kt feedstock, of which 86% was crop material and 14% was chicken manure (Table 2).

Table 2. Origin of BENAS' digester feedstock (2019).

Type	Mass (kt)
Maize silage	41
Other crops	37.9
Chicken manure	13.3
Total	**92.2**

Biogas production

In 2019 around 20 Mio Nm^3 of biogas were produced (Table 3). About 12 Mio Nm^3 were converted in the combined heat and power (CHP) installation into electrical (27,993 MWh) and thermal (25,518 MWh) energy. About 8 Mio Nm^3 were upgraded to biomethane, which corresponds to an energy production of 37,699 MWh.

Table 3. Biogas production and average biogas composition before purification for the year 2019.

Parameter	Amount
CH_4 (% v/v)	53
CO_2 (% v/v)	46
H_2S (ppm)	83
O_2 (% v/v)	0.1
Total biogas production (Nm^3)	20.4 Mio
Biogas per tonne of feedstock (Nm^3 t^{-1})	222

Gesellschaft für Nachhaltige Stoffnutzung mbH

Horizon 2020

BENAS (Ottersberg, Germany)

Nutrient Recovery & Reuse (NRR) process

After storage in the post-digesters, the digestate is separated by the first screw press in a liquid fraction (LF) and solid fraction (SF) which both are applied on agricultural land. A second way of processing is also possible: in an internal recirculation loop, digestate is fed to the FiberPlus system for removal of NH_3 (detailed description below). In this system, NH_3 and carbon dioxide are brought into contact with gypsum resulting in ammonium sulphate solution and calcium carbonate sludge (Figure 2). The produced N-stripped digestate is separated into an SF and LF, the latter is fed back to the digester. The SF is further processed in a fibre moulding and paper making machine. The resulting product is dried, with excess heat from the CHP installation to remove residual moisture, to the end product low-N fibres. The fibres are suitable for different applications such as production of paper, mulch mats or plant pots.

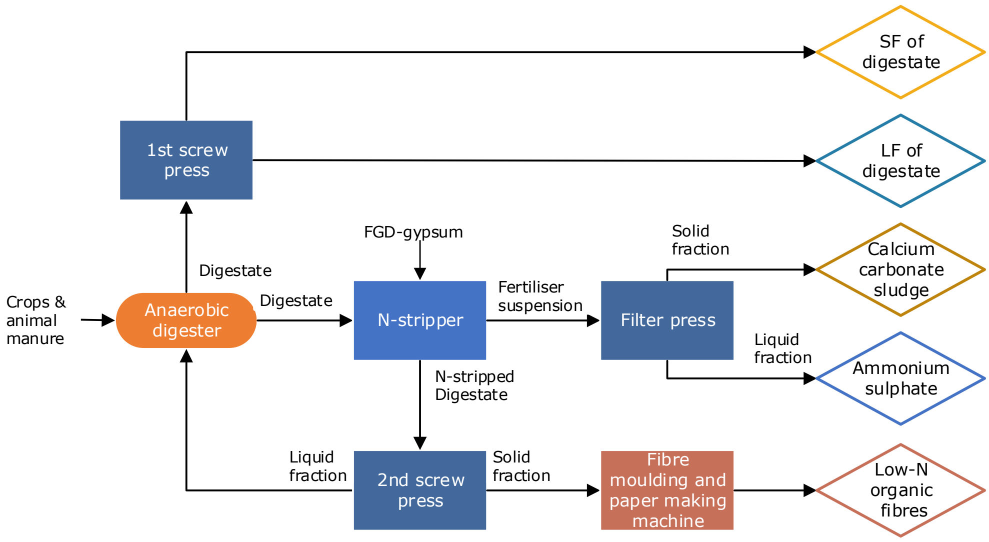

Figure 2. Simplified process flow diagram of BENAS's current nutrient recovery and reuse system.

N-stripping and scrubbing process (FiberPlus system)

In 2007/2008, BENAS installed the FiberPlus system, developed and patented by GNS, in which NH_3 is stripped from digestate without the use of acids, bases or external stripping agents (Table 4). The system consists of an N-stripper and scrubber, filter press and the second screw press. It requires the addition of Flue Gas Desulphurisation-gypsum (FGD-gypsum) to produce two marketable fertilisers: ammonium sulphate solution, with a dry matter content of 22–26%, and calcium carbonate sludge, with a dry matter content of circa 75%. The process does not require an external heat source as it functions solely on the heat produced by the CHP installation. It consumes circa 100 kWh of thermal energy per m^3 of digestate processed. The added FGD-gypsum is a by-product of coal power plants. From 2011 onwards the N-stripped digestate or its LF is fed back to the digester. The advantages of the FiberPlus system are:

- Of the NH_3 in the digestate, 56–85% is stripped and subsequently recovered as ammonium sulphate solution and partly as calcium carbonate sludge;
- NH_3 inhibition of the digester is prevented, increasing the biogas yield by 8%;
- Since October 2016 the FiberPlus system has been expanded with the production of low-N fibres.

Table 4. Technical specifications of the FiberPlus system.

Specification	
Digestate processing capacity	5–25 m^3 h^{-1}
NH_3 content of ingoing digestate	3–5 g L^{-1}
Dry matter content of ingoing digestate	5–12.5 %
NH_3 striping efficiency	56–85%
Production capacity of ammonium sulphate solution	5–40 t d^{-1}
Production capacity of calcium carbonate sludge	1.5–14 t d^{-1}

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 ran for 4 years.

Horizon 2020

BENAS (Ottersberg, Germany)

Status of construction

To make the plant's electricity generation more flexible in time, BENAS has installed an additional biogas storage tank. Also, two additional CHP installations have been installed and all digesters and storage tanks have been fitted with new roofs.

Products and market

In 2019, BENAS produced 1,128 t of calcium carbonate sludge, 3,545 t of ammonium sulphate solution and <1 000 t of low-N fibres. The composition of the ingoing digestate and produced end products is given in Table 5.
The ammonium sulphate solution is recommended by GNS as a good fertiliser because:

- its neutral pH is well tolerated by plants;
- its dry matter content of 22–26% does not lead to evaporative crystallisation when applying it directly on crops;
- It can be used for producing mineral fertiliser solutions or for increasing the N content of manure or digestate.

Also, the field application of calcium carbonate sludge has the following advantages:

- calcium is an important plant nutrient;
- it increases soil pH and enhances nutrient availability without causing alkalinisation because it dissolves only in acidic soils;
- it improves soil structure and soil biological activity.

Table 5. Composition of the ingoing digestate and produced end products at BENAS (February 2018 – February 2020).

	Digestate	Liquid fraction of digestate	Solid fraction of digestate	Calcium carbonate sludge	Ammonium sulphate solution
Dry matter (g kg^{-1})	105	94	248	690	221
Organic matter (g kg^{-1})	83	68	222	29	0.35 (TOC)
Total N (g kg^{-1})	7.4	7.2	7.9	13	45
Total P (g kg^{-1})	1.9	1.6	1.8	0.17	0.0027
Total K (g kg^{-1})	6.8	6.4	8.9	0.4	0.0059
Total S (g kg^{-1})	1.2	1.0	1.4	28	58

Economic benefits

GNS calculated that the replacement of conventional fertiliser with ammonium sulphate solution and calcium carbonate sludge saves BENAS about € 300,000 per year (Table 6). In addition, the sale of low-N fibres is estimated to generate around € 82,000 of revenues per year. A higher biogas yield is achieved due to reduction of NH_3 inhibition. Also, a higher intake of chicken manure, a low-price feedstock due to its high N content, is possible. Due to the lower N content, more SF and LF of digestate can be applied per ha of arable land which results in lower storage and transport costs for BENAS.

Table 6. Economic benefits of the NRR system.

Benefit	€ y^{-1}
Use of ammonium sulphate solution	244,000
Use of calcium carbonate sludge	63,000
Revenues from low-N fibres	82,000
Higher biogas yield	321,000
Higher fraction of N-rich digester feedstock	385,000
Heat utilisation (EEG 2004, Renewable Energy Law)	176,000
Total savings	**1,271,000**

Sustainability goals

BENAS is committed to reaching the following targets:

- Decreasing overall greenhouse gas emissions by producing renewable energy and lowering CO_2 emissions from transport of digestate or its fractions;
- Contributing to a more stable electricity grid via flexible electricity generation in time;
- Closing the nutrient cycle by using the produced end products on their own fields for production of energy crops';
- Production of low-N fibres as an environmental friendly alternative for wood fibres or peat.

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 ran for 4 years.

Horizon 2020

Monitoring data: total mass and nutrient mass flows

Total mass (Figure 3) and nutrient mass (Figure 4) flows were calculated for the NRR system of BENAS for the period January 2019 – April 2019. This was done to evaluate the overall performance of the plant and the separation efficiencies of the individual process units. Of the total N in the digestate processed in the N-stripper, 31% ended up in the ammonium sulphate solution and 4.5% in the calcium carbonate sludge. Of the NH_4-N in the digestate processed in the N-stripper, 57% ended up in the as ammonium sulphate solution and 7.8% in the calcium carbonate sludge.

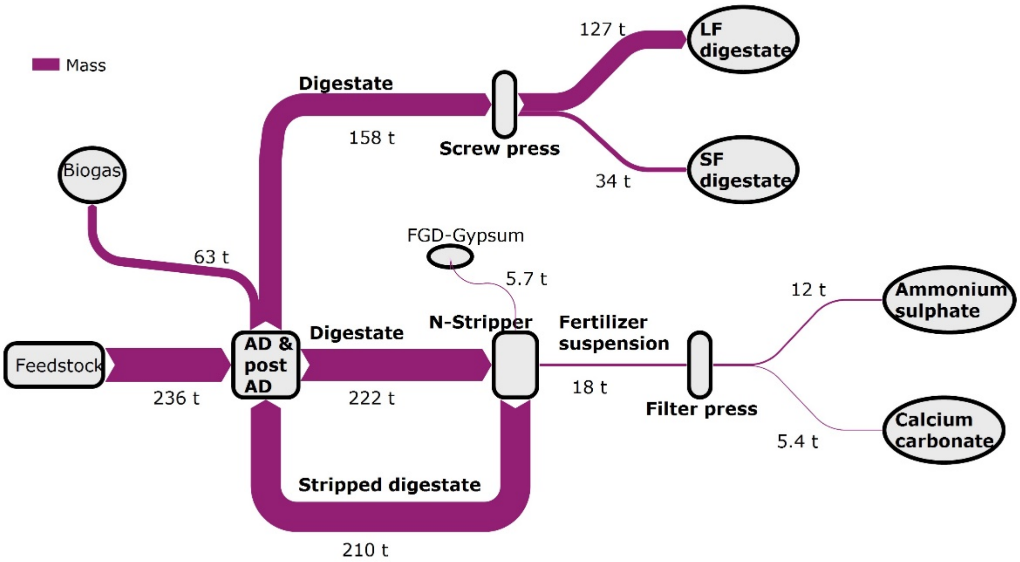

Figure 3. Total mass flows of the nutrient recovery and reuse system at Benas in tonnes (t) per day.

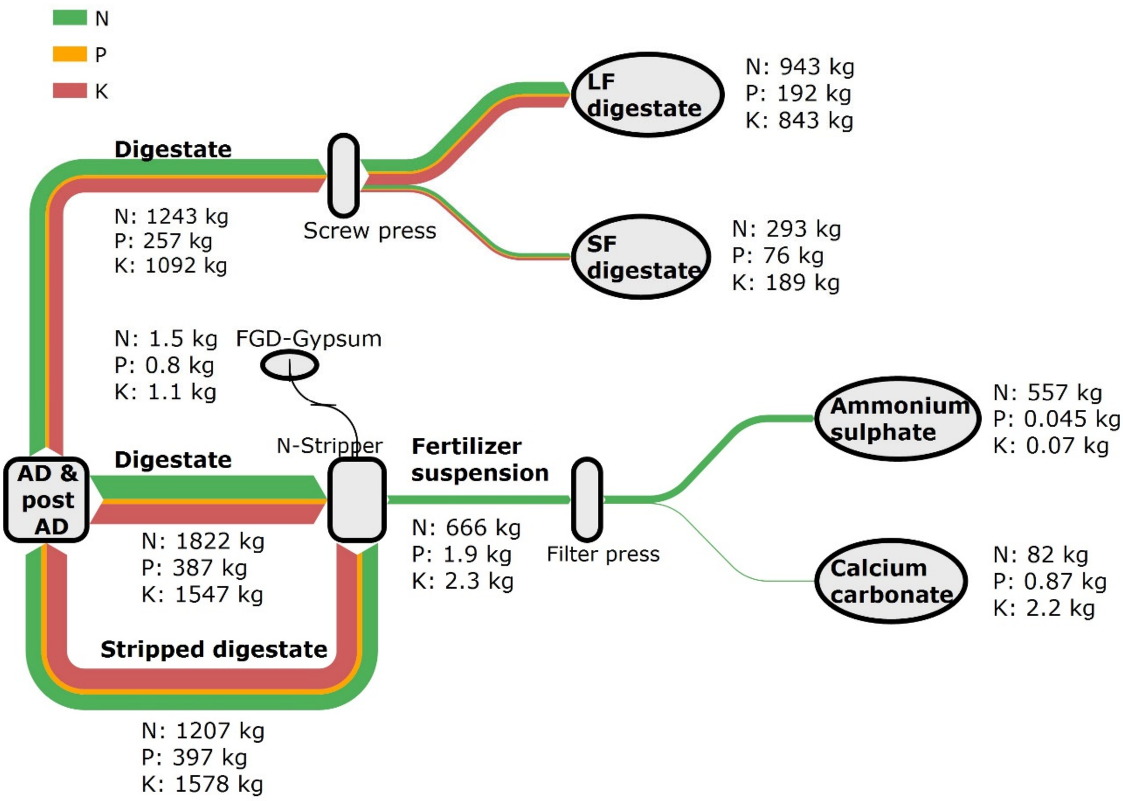

Figure 4. Total nitrogen (N), total phosphorus (P) and total potassium (K) mass flows of the nutrient recovery and reuse system at BENAS in kilogram (kg) per day.

BENAS (Ottersberg Germany)

Monitoring data: energy balance

In 2019 the plant generated 25,518 MWh of thermal energy, of which 21% was subsequently consumed by the N-stripper. The remainder was used for cooling of the stripping gas and biogas, for heating of the digesters and buildings and for drying of grain and wood chips. The plant generated 27,993 MWh of electricity of which only 6% was used by the plant. The remainder was sold via the national grid (Figure 5).

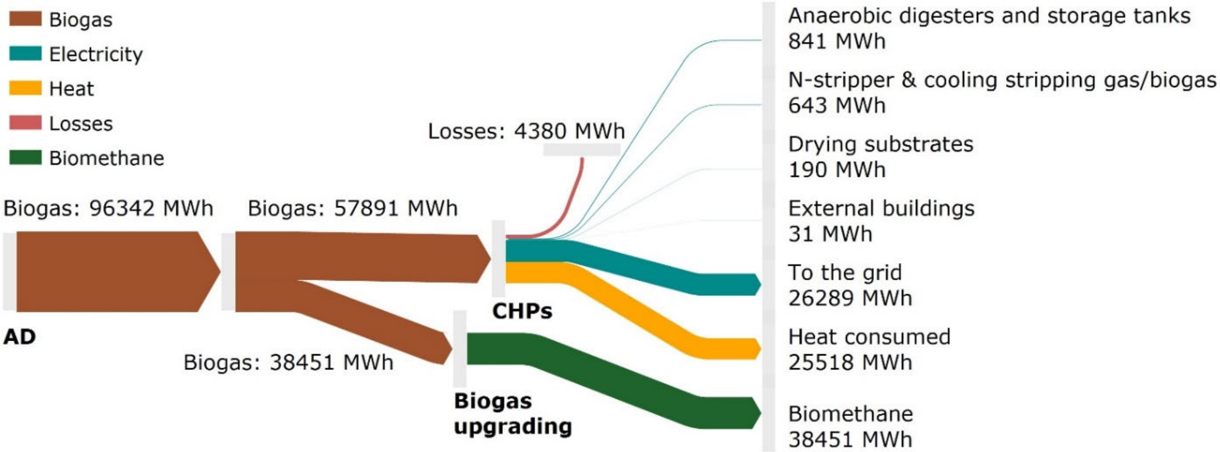

Figure 5. Energy balance of the anaerobic digestion (AD) and nutrient recovery and reuse system at Benas for the year 2019.

Key Performance Indicators (KPIs)

Economic KPIs are simple tools to gain insight into a company's economic performance:

KPI_1: EBIT (Earnings Before Interest and Taxes) margin as % of revenues.
KPI_2: EBITA (Earnings Before, Interest, Taxes and Amortisation) margin as % of revenues.
KPI_3: Substrate (financial) productivity → total gross revenues per tonne of feedstock.
KPI_4: Biogas (financial) productivity → net revenues of biogas (energy / green certificates) per cubic meter of biogas delivered.
KPI_5: Digestate (financial) productivity → net costs/revenues generated by digestate per tonne of feedstock.

Table 7. Economic KPIs of BENAS's plant.

KPI	
EBIT margin	13%
EBITA margin	36%
Substrate productivity	€80 / tonne feedstock
Biogas productivity	€0.38 / Nm^3 biogas
Digestate productivity	€-0.95 / tonne feedstock

The high biogas productivity of the plant results in the highest substrate financial productivity of all SYSTEMIC demonstration plants. However, the high total costs for insurance, maintenance, personnel and consumption of electricity and FGD-gypsum have a large impact on the EBIT and EBITA.

More information on the economic KPI analysis is available in deliverable D2.4: *'Final report on the development and application of economic key performance indicators (KPIs)'.*

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Horizon 2020

SYSTEMIC
Circular solutions for biowaste

Waterleau NewEnergy (Ypres, Belgium)

A short introduction to Waterleau

Waterleau NewEnergy is an environmental services company in the field of water, air and waste treatment. Waterleau NewEnergy runs an anaerobic digestion (AD) plant in Ypres (West Flanders, Belgium). The plant is operational since 2012 and can digest roughly 120 kilotonnes (kt) of feedstock per year at mesophilic conditions.

Table 1. Technical information of the biogas plant.

Characteristics	
Year of construction	2012
Maximum power output	3,2 MW_e
Digester volume	12 000 m^3
Digestion type	Mesophilic digestion

Drivers for nutrient recycling

The province of West Flanders is a nitrate vulnerable zone with intensive pig husbandry and a total animal manure production in terms of nitrogen (N) that exceeds the amount of manure that can be applied on agricultural land within legal limits. As a consequence, part of the produced manure and manure derived digestate has to be either exported or reduced in N content. Transport of manure or digestate is expensive, Waterleau NewEnergy has therefore implemented a nutrient recovery and reuse (NRR) system at the plant. The system reduces the total volume of streams that have to be transported and concentrates the nutrients by producing purified water.

Figure 1. Aerial photo of the demonstration plant Waterleau NewEnergy.

At Waterleau NewEnergy, digestate is upgraded into valuable biobased fertilisers:

- Dried solid fraction (SF) of digestate, which is mixed with part of the evaporator concentrate. The resulting blend is composted externally and thereafter exported to France;
- The remainder of evaporator concentrate is exported to the Netherlands;
- Condensed ammonia water is sold as reductant in the DeNOx system of a local incineration plant;
- Reverse osmosis (RO) permeate is reused as process water, as cooling water for the recovery of heat or it is discharged after polishing.

Feedstocks

The co-digestion capacity is 120 kt feedstock (organic substrate) per year. In 2020, the plant digested about 71 kt feedstock, of which 30% was animal manure (Table 2).

Table 2. Origin of Waterleau NewEnergy's digester feedstock (2020).

Type	Mass (kt)
Manure and solid fraction of manure	21
Sludge from industrial wastewater treatment plants and other biowastes	47.8
Glycerine and molasses	1.1
Total	**71**

Biogas production

In 2020 around 10 Mio Nm^3 of biogas were produced (Table 3). The biogas was converted by a Combined Heat and Power (CHP) installation into electrical (21,313 MWh) and thermal (22,800 MWh) energy.

Table 3. Biogas production and average biogas composition before purification for the year 2020.

Parameter	Amount
CH_4 (% v/v)	55
CO_2 (% v/v)	45
H_2S (ppm)	<200
O_2 (% v/v)	<1
Total biogas production (Nm^3)	10.3 Mio
Biogas per tonne of feedstock (Nm^3 t^{-1})	145

WATERLEAU

Horizon 2020

Waterleau NewEnergy (Ypres, Belgium)

Nutrient Recovery & Reuse (NRR) process

The feedstock is pre-heated to 40 °C and mixed to an optimal DM content before being pumped into the anaerobic digesters. The residence time in the digester is around 30 days and an additional 10 days in the post-digester. The produced digestate is hygienised (1 hour at 70 °C) and subsequently separated in a solid fraction (SF) and a liquid fraction (LF) of digestate by means of a decanter centrifuge. The SF of digestate is dried in a rotating disc dryer (Hydrogone® dryer) which can evaporate 1–1.8 t of water per hour. In this type of dryer there is no direct contact between hot air and the SF of digestate. Instead, the SF of digestate is mixed with discs filled with steam or hot oil. This reduces ammonia (NH_3) losses due to drying.

The exhaust air from the dryer is treated by an air scrubber, thereby producing air scrubber water. The LF of digestate, together with the air scrubber water and the evaporated water from the dryer flow to an aerobic treatment tank for lowering of the mixture's biochemical oxygen demand. The effluent subsequently flows to an evaporator which operates at 50-60 °C. NH_3 and water partially evaporate and are largely separated from each other based on volatility in the three consecutive stages of the evaporator. Condensation of these vapours in the condenser results in the following process streams: condensed ammonia water, process water and evaporator concentrate.

The condensed ammonia water is sold as reductant in the DeNOx system of a local incineration plant. The process water flows to an RO installation and the resulting permeate is either reused within the NRR system or discharged. The evaporator concentrate is partly mixed with the dried SF of digestate and subsequently composted and exported and partly exported directly.

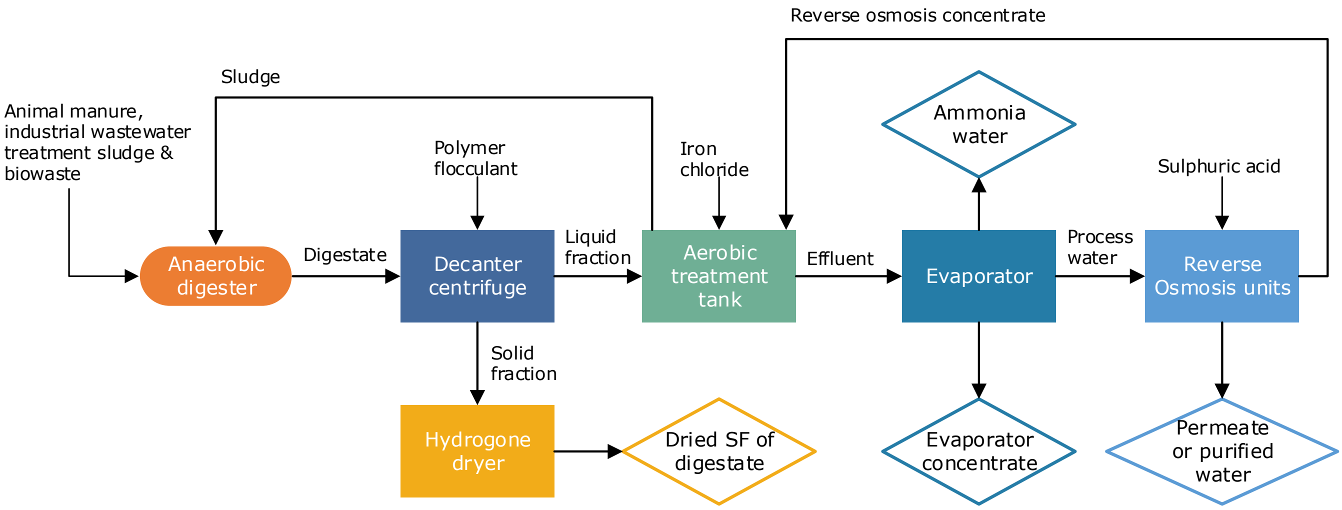

Figure 2. Simplified process flow diagram of Waterleau NewEnergy's current nutrient recovery and reuse system.

Status of construction

The biogas plant was built in 2006 and included the digesters and the current NRR system, except the RO installation. In 2013, the hygienisation tanks were moved from upstream to downstream of the digesters. In 2017, the RO installation was constructed to allow polishing of the process water produced by the evaporator.

Waterleau NewEnergy currently seeks a method to dewater the evaporator concentrate with the excess heat produced by the CHP installation. An alternative is acquiring additional dried SF of digestate of other biogas plants to allow mixing of all evaporator concentrate with dried SF of digestate.

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Horizon 2020

Waterleau NewEnergy (Ypres, Belgium)

Products and market

The SF of digestate is dried and composted in Flanders. This product has a positive effect on the dry matter (DM) content and structure of the compost. The proximity of WNE to many composting companies and the French border reduces transport costs, and the product containing concentrated nutrients is well accepted in northern France.

The evaporator and RO produce permeate or purified water, condensed ammonia water and an evaporator concentrate. Condensed ammonia water is not suitable as fertiliser, because of its high pH (>10) and therefore also high risk of NH_3 volatilisation and crop burning. The product is sold to a Belgian waste incineration plant and used as reductant for the DeNOx exhaust gas treatment system. The evaporator concentrate with high potassium (K) concentration is traded as fertilizer to the Netherlands. Alternatively, it is mixed with the dried SF of digestate and exported to France.

Table 5. Composition of the ingoing digestate and produced end products at Waterleau NewEnergy (June 2020 – December 2020).

	Digestate	Dried solid fraction of digestate	Evaporator concentrate	Ammonia water	Purified water
Dry matter (g kg^{-1})	57	904	187	-	-
Organic matter (g kg^{-1})	33	637	91	-	-
Total N (g kg^{-1})	6.5	29	13	96	0.63
Total P (g kg^{-1})	1.0	24	2.1	0.0005	0.000024
Total K (g kg^{-1})	3.9	15	22	0.00055	0.000073
Total S (g kg^{-1})	0.93	10	11	0.5	0.0022

Economic benefits

Long distance transport of digestate from the province of West Flanders to nutrient demanding regions is costly. The implemented NRR system enables Waterleau NewEnergy to concentrate nutrients in certain end products and to reduce the total volume of digestate and its end products that need to be transported, thereby saving costs for transport. Overall, per tonne of processed digestate, between €11–16 of disposal costs are saved by the current NRR system compared to conventional disposal of unseparated digestate

Table 6. Estimated disposal costs for the end products produced at Waterleau NewEnergy for the current NRR system and for the scenario without NRR system for the year 2020.

Without NRR system	**t y^{-1}**	**€ y^{-1}**	**€ t^{-1} digestate**
Digestate	65 000	975 000 – 1 300 000	15 – 20
With NRR system	**t y^{-1}**	**€ y^{-1}**	**€ t^{-1} digestate**
Evaporator concentrate (30%) + dried solid fraction of digestate (100%)	2 500 + 3 000	0	0
Evaporator concentrate (70%)	5 833	244 986	3.8
Condensed ammonia water	724	7 240	0.11
Total		258 610	3.9

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Horizon 2020

Monitoring data: total mass flows

Total mass flows (Figure 3) were calculated for the NRR system of Waterleau NewEnergy for the period June – October 2020. This was done to evaluate the overall performance of the plant and the separation efficiencies of the individual process units.

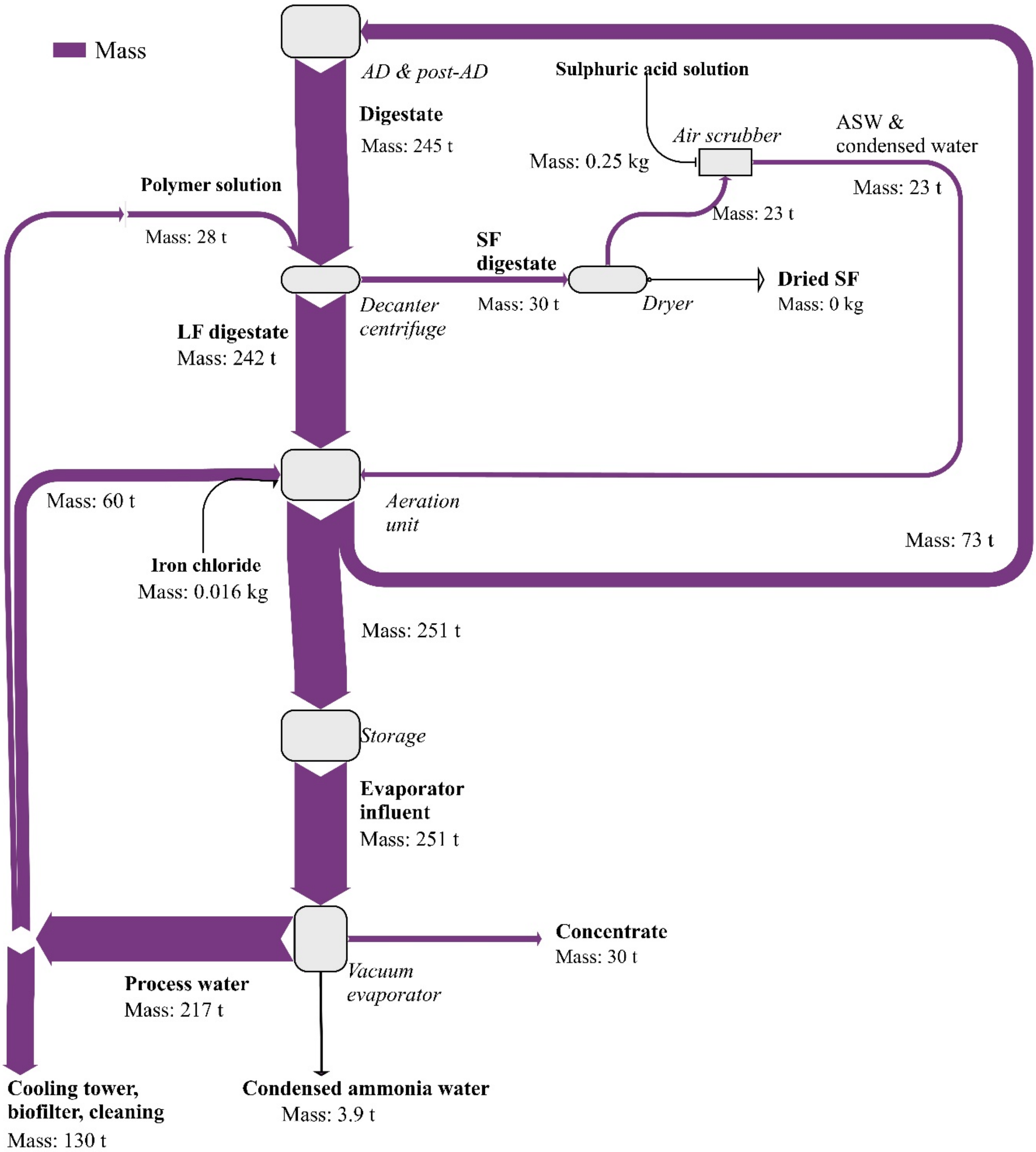

Figure 3. Total mass flows of the nutrient recovery and reuse system at Waterleau NewEnergy in tonnes (t) per day.

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Horizon 2020

Monitoring data: nutrient mass flows

Nutrient mass flows (Figure 4) were calculated for the NRR system of Waterleau NewEnergy for the period June – October 2020. This was done to evaluate the overall performance of the plant and the separation efficiencies of the individual process units.

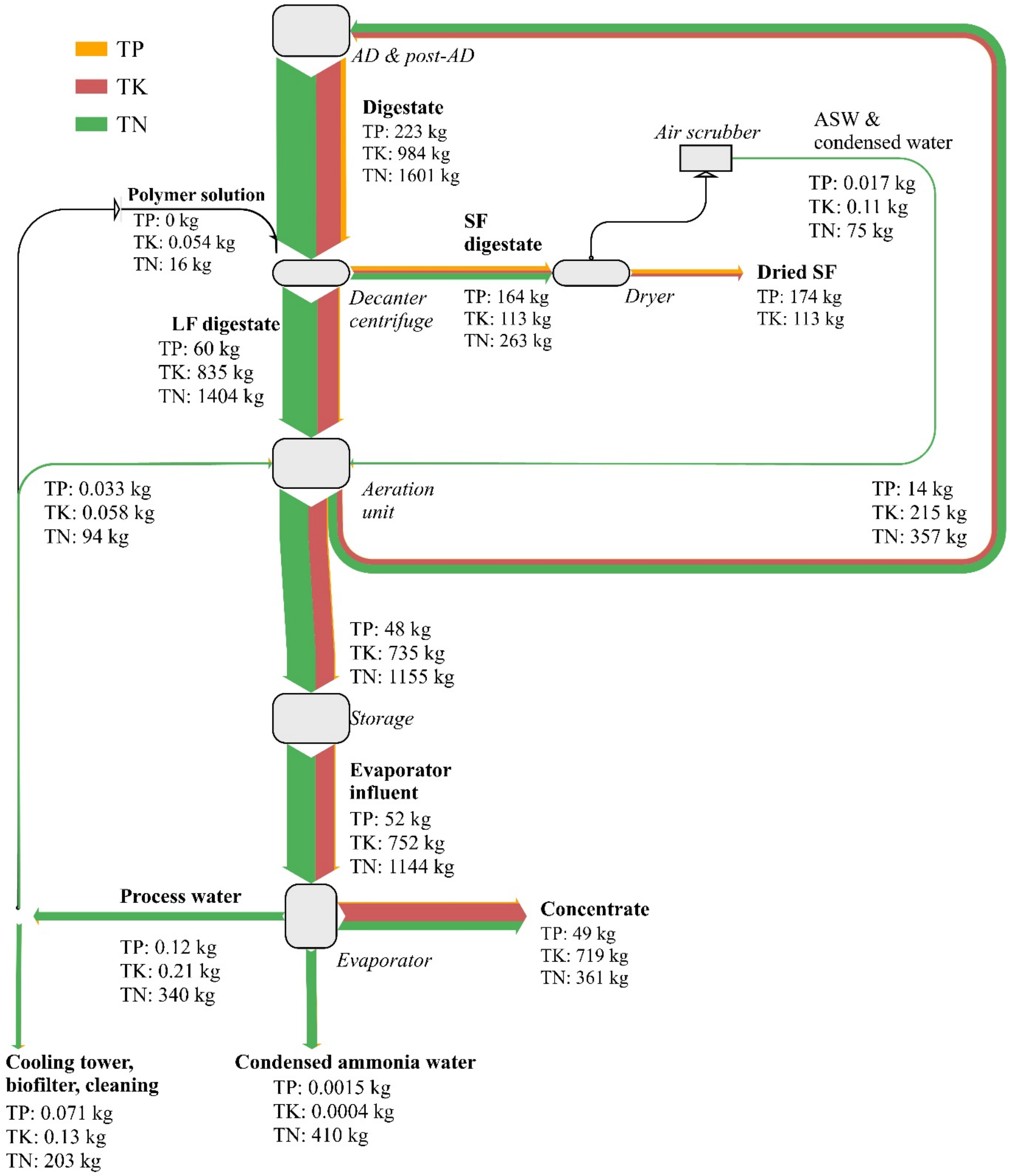

Figure 5. Total nitrogen (TN), total phosphorus (TP) and total potassium (TK) mass flows of the nutrient recovery and reuse system at Waterleau NewEnergy in kilograms (kg) per day.

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Horizon 2020

Waterleau NewEnergy (Ypres, Belgium)

Monitoring data: energy balance

In 2020 the plant generated 21,313 MWh of electricity, of which 32% was consumed by the NRR system. More specifically, 14% by the evaporator, 10% by the dryer, 5.8% by the aerobic treatment tank, 1.2% by the decanter centrifuges, 0.93% by the hygienisation tanks and 0.4% by the RO installation. All produced heat was used on-site by the hygienisation tanks (12%), dryer (31%) and evaporator (56%).

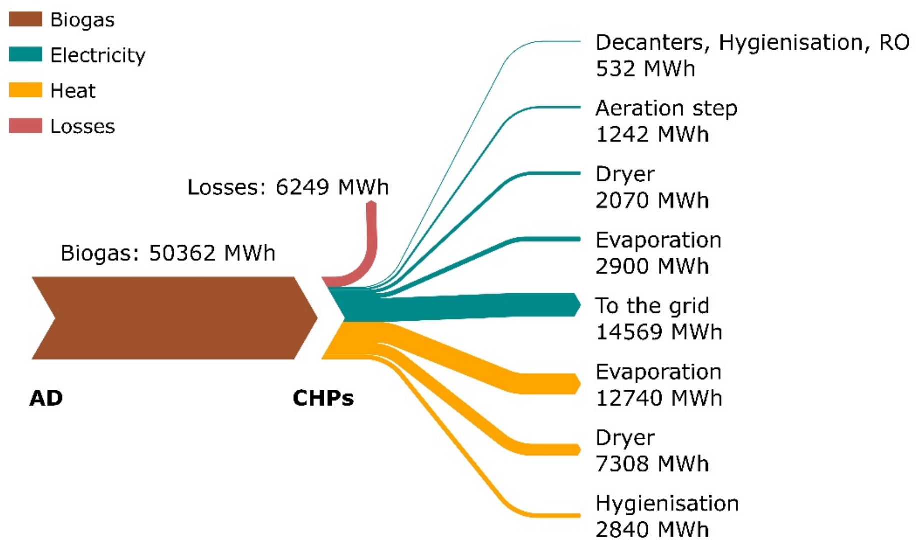

Figure 6. Energy balance of the anaerobic digestion (AD) and nutrient recovery and reuse system at Waterleau NewEnergy for the year 2020.

Key Performance Indicators (KPIs)

Economic KPIs are simple tools to gain insight into a company's economic performance:

KPI_1: EBIT (Earnings Before Interest and Taxes) margin as % of revenues.
KPI_2: EBITA (Earnings Before, Interest, Taxes and Amortisation) margin as % of revenues.
KPI_3: Substrate (financial) productivity → total gross revenues per tonne of feedstock.
KPI_4: Biogas (financial) productivity → net revenues of biogas (energy / green certificates) per cubic meter of biogas delivered.
KPI_5: Digestate (financial) productivity → net costs/revenues generated by digestate per tonne of feedstock.

Table 7. Economic KPIs of Waterleau NewEnergy's plant.

KPI	
EBIT margin	8%
EBITA margin	19%
Substrate financial productivity	€62 / tonne feedstock
Biogas financial productivity	€0.33 / Nm^3 biogas
Digestate financial productivity	€-7.1 / tonne feedstock

The plant has a relatively high substrate financial productivity and a relatively low digestate financial productivity compared to the other SYSTEMIC demonstration plants. Digestate financial productivity is relatively low because of the costs for processing of the digestate and disposal of the end products.

More information on the economic KPI analysis is available in deliverable D2.4: *'Final report on the development and application of economic key performance indicators (KPIs)'.*

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Horizon 2020