Biomass for Energy

Case Study Report

Nutrient recovery from digestate

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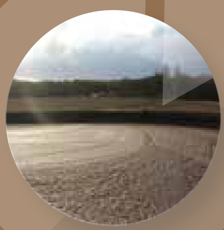

Improving ***sustainable biomass utilisation*** *in North West Europe*

Colophon

This report was compiled in the framework of action 3 of the ARBOR* project.

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This report further received input from the other ARBOR partners on specific aspects related to the regional transferability of the investigated case study results. Willem Dhooge (FlandersBio, BE) also helped with text corrections and lay-out.

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Please check **www.arbornwe.eu** for the other reports that have been compiled within ARBOR:

- Five case study reports on a diversity of subjects like nutrient recovery, low impact energy crops, agro side streams, synergy parks and biomass closed-loop systems.
- An update of the 2012 Benchmark report on biomass for energy use in NWE
- A strategies report on biomass for energy for regional authorities in the North West European region.

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1. Introduction

Due to the historic presence of intensive livestock production and the limited amount of arable land for manure disposal, nitrate pollution in certain European areas is considerable. The European Nitrates Directive, implemented in 1991, intended to improve water quality in Europe by preventing pollution of ground- and surface water by nitrate leaching from agriculture. This has forced local administrators and government to introduce stringent regulations regarding the use of manure (and later on digestate), resulting in national action plans and the defining of vulnerable zones. The Flemish action plan, for example, consists of an obligation to process manure in such a way that the nitrogen present is not returned on Flemish agricultural soil after treatment, but is either exported, used on non-agricultural land (e.g. in gardens or parks) or converted to nitrogen gas or to a mineral fertiliser. These restrictions, combined with the presence of intensive livestock, imply that anaerobic digestion plants in Flanders (and other nutrient rich areas), may not, or only sparingly, return digestate as a fertilizer in its crude, unprocessed form and have to invest in digestate processing techniques.

More recently, the focus in digestate processing techniques has switched from mere processing towards valorization techniques that recover a maximal amount of nutrients (N, P, K).
This development is triggered by an increasing worldwide awareness of the depletion of mineral resources (such as phosphorus) and the volatile price of fossil-based mineral fertilizers.
Mineral fertilizer use in Europe is high, even in regions with local nutrient surpluses where farmers pay to export or destroy nitrogen in their farmyard slurry. The reason for this is twofold, first of all animal manure spreading is limited to 170 kg of N/ha according to the Nitrates Directive (in vulnerable zones) and second of all nutrient availability and composition in manure can differ from crop requirements. Estimates of the current phosphorus and potassium reserves are highly uncertain, but based on population growth and future nutrient demand, it is predicted that depletion will occur within 93 to 291 years for P and 235 to 510 years for K (Fixen and Johnston, 2012; Van Vuuren *et al.*, 2010; Villalba *et al.*, 2008; Smit *et al.*, 2009). Geopolitical moves can however shift this date forward, making nutrient scarcity an imminent threat which is exemplified by the fact that phosphorus was recently added to the EU 'critical raw materials' list.

A momentum has been created in which upcycling of digestate derivatives towards high quality fertilizers is aspired. The current challenges are to achieve optimal recovery and recycling of nutrients from digestate in a sustainable way enabling marketing and valorisation in an adjusted legal framework.

2. Inventory of nutrient recovery techniques

In the framework of the ARBOR project, an inventory of techniques that have been tested either full-scale, pilot scale or lab scale, has been elaborated. For the full report 'Inventory: techniques for nutrient recovery from digestate' by Lebuf *et al.* (2013), please see http://arbornwe.eu/downloads

In the report the following definition for a nutrient recovery technique is proposed: techniques that create an end-product in which nutrients are present in a higher concentration or different NPK-ratio than before processing or those that separate the envisaged nutrients from organic compounds, with the aim to produce an end-product that is fit for use in chemical or fertiliser industry or as a mineral fertiliser replacement.

From the nutrient recovery techniques discussed in the inventory report, only acid air washers, membrane filtration plants and ammonia stripping plants are currently working at full scale at anaerobic digestion plants in Flanders. However, they may need further technical fine-tuning, especially towards energy saving and chemical use. In addition, adjusting the process in a way that the characteristics of the end-products can be made more client-specific and more predictable, is an important challenge. A breakthrough in full-scale plants is to be expected for phosphorus precipitation. In the long run also electrochemical nutrient separation, several membrane separation techniques and biomass production could become part of commonly used digestate processing techniques. The extraction of phosphorus from ashes or biochar seems less promising, because it is questionable if combustion/ pyrolysis of digestate is a sustainable treatment option (due to nitrogen loss) and if this should be encouraged. However, extraction techniques could also be applied on the (dried) solid fraction of digestate.

For all techniques described it is essential to put attention on their marketing value towards industrial or agricultural end-users. To be economically profitable, the treatment cost should be less than the current costs for manure disposal. Best case is that manure turns into a product with a positive value, for example if the price allocated to the recovered nutrients is in accordance with the market price of N, P and K in mineral fertilizers.

3. Physicochemical characterisation of recovered products

Despite the potential economic and ecologic benefits, closing nutrient cycles within the agricultural sector by introducing bio-based fertilisers seems to be difficult to realise due to, among others, lack of insights in the composition and properties of these products. Consequently, within ARBOR a report was dedicated to the physicochemical properties of digestate and its derivatives and field experiences. Below you can find a synthesis focussed on the following products which were used in the ARBOR field trials: ammonium sulphate, the liquid fraction (LF) of digestate, a mixture of digestate and the LF of digestate, struvite and the effluent of constructed wetlands.

Ammonium sulphate, which is waste water resulting from ammonia-removal from manure or digestate using an acidic air scrubber, is a potential N-S-fertiliser. Reuse of the N-K-rich, but P-poor liquid fraction of digestate after mechanical separation of raw digestate or a 50/50 mixture of raw digestate and LF-digestate might be of important interest, since phosphorous application becomes more and more stringent in the European legislation (Vaneeckhaute *et al.*, 2013). Furthermore, phosphorous can be removed from waste water and (digestate) slurry by adding magnesium, which results in the precipitation of ammonium magnesium phosphate ($NH_4MgPO_4 \cdot 6H_2O$), also known as struvite, a slow releasing granular P-fertiliser. The current practice of struvite precipitation in Flanders, however, is limited to P-removal (precipitation) from industrial and municipal wastewater (Lebuf *et al.*, 2013). Finally, the effluent from constructed wetlands (CW) is the end-product of the final processing step, after biological treatment, of animal manure to dischargeable water that in large quantities can be used as a K-fertiliser (Sigurnjak *et al.*, 2014).

In frame of ARBOR these products (and combinations of products) were used in open field trials and a greenhouse trial in Flanders. An elaborate description of the product characterisations and field experiences can be found in the ARBOR-report on physicochemical characterisation and market analysis of recovered nutrients from digestate. Below the key messages and observations are listed. Table 1 provides a summary of the key characteristics of the products under study.

Table 1: Physicochemical characterisation of the recovered products on a fresh weight (FW) basis, (n=2)

	Field trial				Greenhouse trial			
	Pig slurry	Mix dig/LF-dig	LF-dig	AmSul	Effluent CW	Struvite	LF-dig	AmSul
DW (%)	10	6.2	2.5	-	0.46	92	3.3	33
OC (%)	42	38	25	-	3.2	24	23	50
pH	7.8	8.2	7.4	2.5	7.8	7.3	8.6	2.4
EC (mS cm^{-1})	35	29	34	157	7.1	0.93	41	262
TN (g kg^{-1} FW)	8.1	4.7	3.6	30	0.02	51.5	5.34	85.8
Mineral N (%)	69	66	77	100	15	2.3	85	100
TP (g kg^{-1} FW)	2.4	0.9	0.27	-	0.004	213	0.86	0.11
K_2O (g kg^{-1} FW)	4.4	2.6	3.5	-	1.44	10.8	4.41	0.18

AmSul= ammonium sulphate; dig= digestate; LF= liquid fraction; CW= constructed wetland

4. Field trials with recovered products

The recovered products as stated in point 3 were used in respectively an open field trial and a greenhouse trial. This kind of research is crucial to evaluate the impact of applying digestate derivatives instead of mineral fertilisers and/or animal manure (traditional fertilisation) on crop yield and soil quality and can serve as a katalysator towards farmers.

4.1 Open field trial with energy maize (2011)

In this field trial eight different fertilisation scenarios were compared (Sc1-8) in four replicate subplots (n = 4) randomized on a 0.8 ha sandy-loam field In Wingene. Based on the soil characteristics before the field trial, the fertilising advice was formulated at 150 kg ha^{-1} effective N, 270 kg ha^{-1} K_2O and 30 kg ha^{-1} MgO. For phosphate, the maximum allowable dosage of 80 kg ha^{-1} for the cultivation of maize on non-sandy soils was set forward as described in the Flemish Manure Decree was respected (Vaneeckhaute *et al.*, 2013). The set-up summary of the field trial can be found in Table 2.

Table 2: Fertilisation scenarios (ton/ha)

Scenario	Mineral start[b]	Mineral fertiliser[c]	Animal manure	AmSul	Mix dig + LF dig	LF dig
1 (ref)[a]	x	x	x			
2	x	x	x	x		
3		x	x	x		
4	x	x			x	
5	x	x		x	x	
6		x		x	x	
7	x	x	x			x
8		x	x			x

AmSul= ammonium sulphate, dig= digestate, LF= liquid fraction

[a] The reference scenario is traditional fertilisation with animal manure and synthetic (mineral) fertiliser
[b] The mineral start fertiliser was ammonium-nitrate (27% N)
[c] The mineral fertiliser consisted of ammonium-nitrate (27% N) and patent-kali (30% K_2O, 10% Mg).

In terms of crop yield no significant differences in the fresh weight of the crops were observed at the 5% level between the eight treatments. A similar observation was made with regards to dry weight and crop length. Overall scenario 7 showed the highest average dry weight yield and plant length throughout the whole experiment. The different fertilisation scenarios had no significant impact on the biogas potential (m^3 ha-1) of the energy maize at the harvest, although the energetic potential for scenario 4-7 was slightly higher as compared to scenario 1-3, due to the higher fresh weight biomass yield (Vaneeckhaute *et al.*, 2013).

Besides the impact on crop quantity and quality it is utmost importance to safeguard the impact of using digestate derivatives on soil fertility and soil quality. No significant differences in N-uptake by the plant could be observed, demonstrating that air scrubber water can be a valuable substitute for synthetic fertilizer nitrogen. Furthermore, nitrogen balances were similar for each scenario and in equilibrium, indicating that the amount of nitrate-leaching was not influenced by the fertiliser type. However, modelling of N-dynamics with NDICEA showed that average nitrate-leaching was slightly lower, except for scenario 7, compared to the reference (Vaneeckhaute et al., 2013).

The P_2O_5-content in digestate and derivatives seems to be more stable in time, which is interesting in terms of fertiliser application. Although significantly less P_2O_5 was applied to the soil in scenario 4-6, a higher crop P_2O_5-uptake was observed in these scenarios. This could be attributed to the higher relative amount of mineral P_2O_5 to total P_2O_5 in the digestate/LF-digestate mixture (50/50) than in animal manure (Vaneeckhaute *et al.*, 2013).

A similar effect was found for K_2O. The crop K_2O-uptake was significantly higher for scenario 4-6 compared to the reference. Interestingly, in these scenarios approximately three times less synthetic K_2O was used. This could lead to serious economic and ecologic benefits. As for P_2O_5, also the relative amount of mineral K_2O to total K_2O was higher in the digestate/LF-digestate mixture in comparison to animal manure (Vaneeckhaute *et al.*, 2013).

Next to N, P_2O_5 and K_2O, also S is an essential macronutrient for plants. However, too high doses of sulphate could also lead to salt accumulation in soils. In scenarios 2, 3, 5 and 6, where air scrubber waste water was used, the S-supply was higher than the crop demand, resulting in a potential S-surplus on the soil balance. Reversely, in the scenarios where no air scrubber water was used the crop demand was higher than the S-supply by manure application, resulting in a net S-extraction from the soil. Up to now no significant differences in soil S-content and soil pH were observed during the growing season and at the harvest (Vaneeckhaute *et al.*, 2013).

For all reuse scenarios, the calculated economic benefits were significantly higher than for the reference (scenario 1), whereas the GHG-emission and energy use were significantly lower. Therefore, the application of bio-based fertilisers in agriculture can result in significant economic benefits for the agriculturist, as well as ecologic benefits regarding energy use and GHG-emission reduction. The economic and ecologic benefits were the highest for scenario 8, respectively 3.5 and 4.4 times higher than the reference, since both synthetic N and K_2O were completely eliminated in this treatment (Vaneeckhaute *et al.*, 2013). More detailed information can be found in the ARBOR-report on physicochemical characterisation and market analysis of recovered nutrients from digestate and Vaneeckhaute *et al.*, 2013.

4.2 Greenhouse trial with lettuce (2013)

In addition to full-field scale testing the potential of using biofertilisers in a specific greenhouse setting was also examined within the ARBOR project. This study was carried out in two experimental greenhouses of the Provincial Research Centre for Vegetables East–Flanders (PCG) situated in Kruishoutem, Belgium.

The experiment was a greenhouse assay, with a fully randomized design with four replication plots of 10 m^2 (4m x 2.5 m) per treatment. Eight different fertilization treatments were established over two greenhouses (greenhouse 1: one on one replacement mineral fertilizer by biobased product, greenhouse 2: partial or complete replacement mineral fertilizer by combination of biobased products). Based on the soil characteristics before the field trial, the fertilising advice was formulated at 210 kg ha^{-1} N, 125 kg ha^{-1} P_2O_5 and 240 kg ha^{-1} K_2O. For each of the two greenhouses, conventional fertilization treatment using mineral fertilizers (treatments 1a and 1b) was included as a reference (Table 3).

Table 3 : Fertilisation scenarios (kg/10m²)

Scenario	CAN	TSP	Patentkali	Struvite	Amsul	CW effluent	LF dig
Individual treatment (Greenhouse 1)							
1a	x	x	x	-	-	-	-
2	x	-	x	x	-	-	-
3	-	x	x	-	x	-	-
4	x	x	-	-	-	x	-
5	-	x	x	-	-	-	x
Combination treatment (Greenhouse 2)							
1b	x	x	x	-	-	-	-
6	-	-	-	x	x	x	-
7	-	-	x	x	-	-	x
8	-	-	x	x	x	-	-

CAN: calcium ammonium nitrate; TSP: triple superphosphate; AmSul= ammonium sulphate; CW= constructed wetland; LF dig= liquid fraction digestate

Physicochemical assessment of the lettuce showed no significant differences in crop uptake among the eight different fertilisation treatments. The crop nutrient content indicated that the applied bio-based products can fulfil the total nutrient requirements of the crop. Evaluation of crop quality control parameters such as tipburn, yellow leaves, basal rot, bremia, leaf colour, uniformity and volume indicated no significant differences as compared to the reference at harvest time, which is crucial in marketability of the crop. However, in treatments 5 and 7 where LF-digestate was used as N-source, the lettuce had a difficult start, which was still visible at harvest time. The negative influence was notable only with respect to lettuce uniformity and volume. This usually may be a result of two crucial variables in LF of digestate application: EC and the presence of ammonia.

In terms of the soil quality and fertility no statistical difference ($p > 0.05$) was observed for the individual treatment substitutions (greenhouse 1). In contrast, significant differences were observed with respect to NO_3-N and available K in greenhouse 2, where partial or complete substitution was envisaged. In the case of complete substitution of mineral fertilisers in treatment 6, a significantly lower NO_3-N concentration was noticed with respect to reference 1b. This is a consequence of leaching by applying large volumes of effluent from CW ammonium sulphate as a K and N- fertiliser on a moderate surface area of 10m^2. Calculations have indicated that the soil was water-saturated with the required application dosage, which may have caused nitrate leaching in treatment 6 during the growing period, resulting in a low nitrate content at harvest time.
Furthermore, the significant difference in plant available K among the treatments in greenhouse 2 was a result of differences between treatments 6, 7 and 8 in which bio-based products were applied. Individually, treatments 6, 7 and 8 were not statistically different as compared to a reference 1b.
The results of this greenhouse trial indicate that biobased fertilizers can also be valuable in horticulture. Further research is however necessary to confirm these results.

4.3 Conclusions

Recuperation and cradle-to-cradle re-use of macronutrients from digestate-derivatives is an important aspect in the further development of sustainable agriculture and anaerobic digestion. Our experiences in the open field trial with energy maize as well as the greenhouse trial with lettuce indicate that the biobased products under study form valuable substitutes for mineral fertilizers, with similar performance towards crop production, soil quality and fertility. However, further research is necessary to assess the long-term effects and attention should be given to the 'form' and nutrient concentration of the products as this can affect their applicability.

These data form a good basis to open the debate of stimulating bio-based products as nutrient supply in agriculture in European legislation. Further field research is on-going in frame of different NWE projects (ex Biorefine) and national projects (ex MIP) to validate the results and to evaluate the long-term impact on soil quality.

5. Market for recovered products

For a full market analysis, please read ARBOR-report "Physicochemical characterisation and market analysis of recovered nutrients from digestate".

5.1 Agricultural land

In North-West European agriculture both nitrogen, phosphorus and potassium fertilizers are applied. Large-scale recycling of nutrients derived from organic materials and using them as mineral fertilizers offers a lot of opportunities. However, some remarks should be made (Jaeken, 2012):

- Recovered substances often contain 3-5% N, whereas mineral fertilizers often contain up to 27% N. This can result in problems of storing large volumes of diluted recovered N products which means a higher operational cost. On top, questions rise about the stability of recovered N products during longer term storing. Products with a lower N concentration result in less accurate applications on the field.
- Another technical issue that should be dealt with is the lack of in-depth knowledge on the plant availability of certain nutrients in recovered products, such as the ashes of combustion. One should have an exact idea of the solubility of the P present, as well as the plant availability and the amount of heavy metals present.

Examples of interesting products for fertilisation of agricultural land are: untreated digestate (NPK-fertiliser), scrubber water ($(NH_4)_2SO_4$), effluents from biological treatments (containing mainly K and Na), mineral concentrates (7 kg N/ton, no P present) and struvite (mineral P fertiliser).

5.2 Domestic use: home garden products

There are several types of home garden products, which could potentially be substituted by digestate and its derivatives. The composted solid fraction of separated digestate could be used in multi-purpose garden composts for example, or thermally dried and granular digestate could be used as a multi-purpose organic fertiliser for gardens.

5.3 Industrial end-users

Representatives of the mineral NPK-industry (producing nitrogen fertilizers, phosphoric acids, potassium fertilizers, …) agree that efficient use of raw materials is important. However, they put forward some requirements for the use of recycled products in their production processes. They need a homogeneous product in sufficient quantity with a constant composition. Furthermore there are several requirements regarding heavy metals and organic contaminants. In general, replacing fossil-based phosphorus by recovered phosphorus is deemed more feasible than the replacement of air-borne nitrogen by recovered nitrogen.

Producers of organic fertilizers and soil improvers also indicate some crucial aspects for recovery, such as the traceability of the products and phytosanitary requirements.

In feed industry there's an interest in replacing soy by locally produced biomass. Research on algae, duckweed and the black soldier fly is being conducted, but when grown on digestate, there are several legislative hurdles to be tackled first.

6. National and EU policy assessment

6.1 European legislation

6.1.1 Fertilisers Regulation

The Fertilisers Regulation ((EC) No 2003/2003) aims to ensure the free circulation on the internal market of "EC fertilisers" i.e. those fertilisers that meet the requirements of this legislation for their nutrient content, their safety, and their absence of adverse effect on the environment. The Regulation in its current form applies only to inorganic mineral fertilisers. It obliges a Member State to accept products lawfully marketed in another Member State unless the Member State of destination can demonstrate that the product poses a risk for human health or the environment (CSES, 2010). The Fertilisers Regulation does not affect other categories of fertilisers, i.e. "national fertilisers", placed on the market of the Member States in accordance with national legislation. These include organic and organo-mineral fertilisers, liming material but also non-fertiliser products such as growing media and organic soil improvers. "National fertilisers" are covered by Regulation (EC) No 764/2008 on mutual recognition which ensures the intra-Community free movement of goods in the nonharmonised area.

The Regulation is currently under revision as it does not encompass the whole fertiliser market. It has left an important and growing part of the market uncovered. The revised Regulation will widen the scope to include inorganic, organo-mineral and organic fertilisers, organic soil improvers, liming products, growing media, plant bio-stimulants and agronomic fertiliser additives. It will facilitate placing on the market both of organic products containing recycled nutrients (e.g. digestates, composts) and inorganic recovered phosphate products (e.g. struvite, incineration ash). However, clarification is still needed regarding the application of REACH for substances leaving the waste status, more specifically the exemption of certain REACH requirements for "recovered products" (art. 2(7)d of REACH). There is also a need for coherence with the Animal By-Products Directive and the Nitrates Directive.

The European End-of-waste criteria specify when certain waste products cease to be waste and obtain a status of a product (or a secondary raw material). It should be noted that if these criteria are not in place, wastes cannot cease to be waste (under the Waste Framework Directive 2008/98/EC) simply because they respect the Fertiliser Regulation requirements. Therefore they will still be regarded as waste. This means that wastes or products from processed waste would thus remain subject to traceability obligations and other relevant waste legislation unless they meet national end-of-waste criteria (www.phosphorusplatform.eu).

6.1.2 Animal by-products Regulation

The Animal by-products Regulation ((EC) No 1069/2009) lays down instructions for the collection, transportation, stockage, handling, use and removal of animal by-products. Companies executing one of these activities have to be certified according to this Regulation. The Regulation also contains instructions for the trade and transit of animal by-products and derived products.

Animal by-products are divided into 3 categories according to their possible sanitary risks. Manure is labelled as "category 2-material". This means that the owners of a manure processing installation, who want to export their products in the EU, have to be certified by a local certification institute. The end-products have to be pasteurised before exportation (minimum 1h at 70°C) or the competent authority may authorise the use of parameters other than the parameters set out in point 1 of Section 1 of Chapter I of the Animal by-product Regulation and other than the standard transformation parameters, provided that the applicant for such use demonstrates that such parameters ensure adequate reduction of biological risks. That demonstration shall include a validation.

Animal by-products have to be collected, transported and labelled according to the Regulation. During transportation a commercial document must accompany the animal by-products.

6.1.3 Nitrates Directive

In 1991 the European Nitrates Directive (Directive 91/676/EEC) was implemented for all member states. This Directive defines a limit of 50 mg/l of nitrate for surface water. If this limit is not respected in certain Member States they are being condemned by the EU and have to take certain measures. One of the causes of too high nitrates level in ground- and surface water is the amount and the way of applying of animal manure.
The Nitrates Directive defines a fertilizer as a substance containing a nitrogen compound or nitrogen compounds utilized on land to enhance growth of vegetation. It may include livestock manure, the residues from fish farms and sewage sludge. A chemical fertilizer is defined as any fertilizer which is manufactured by an industrial process. Livestock manure is defined as a waste product excreted by livestock or a mixture of litter and waste products excreted by livestock, even in processed form.

DG Environment (in charge of the Nitrates Directive) is preparing a report on the impact of digestate on water quality. The draft report shows that there are certain member states where digestate does not necessarily have an animal manure status, even if animal manure entered the biogas plant. This shows that the status of digestate is merely a national or regional interpretation of the Nitrates Directive (Grauwels, 2014).

6.1.4 Regulation on organic production and labelling of organic products

To evaluate which types of digestate are allowed in organic farming practices, depending on the ingoing types of biomass, this regulation (Regulation (EC) No 834/2007) should be consulted. The following articles can be of importance:

Article 4.b: Organic production shall be based on the restriction of the use of external inputs. Where external inputs are required, these shall be limited to:

- Inputs from organic production
- Natural or naturally-derived substances
- Low solubility mineral fertilizers

Article 12.1.b: the fertility and biological soil activity of the soil shall be maintained and increased by multiannual crop rotation including legumes and other green manure crops, and by the application of livestock manure or organic material, both preferably composted, from organic production

Article 12.1.d: in addition, fertilizers and soil conditioners, may only be used if they have been authorised for use in organic production under Article 16

Article 12.1.e: mineral nitrogen fertilizers shall not be used

Article 16.1.b: The Commission shall, in accordance with the procedure referred to in Article 37(2), authorise for use in organic production and include in a restricted list the products and substances, which may be used in organic farming for the following purposes: as fertilisers and soil conditioners.

6.2 Belgian & Flemish legislation

6.2.1 Royal Decree on Trade in Fertilizers, Soil Improvers and Growing Media

The Fertilisers Regulation ((EC) No 2003/2003) aims to ensure the free circulation on the internal market of This federal law from 28/01/2013 regulates i.a. the trade within Belgium of end-products of manure and digestate processing. It defines that a fertiliser should appear on the list in Annex I of the legislation to be traded. This list contains a description of the essential requirements for a fertiliser. If a certain product does not appear on the list, derogation can be requested. The Federal Government for Public Health, Safety of the Food Chain and the Environment is in charge of the derogation allowances. The Federal Agency for Food Safety certifies the companies trading fertilisers and checks if the fertiliser standards are complied with.

6.2.2 Flemish Manure Decree

The Flemish Manure Decree is the implementation of the EU Nitrates Directive (1991). The Manure Bank is the administration responsible for the implementation of the Manure Decree.

The Manure Decree has been adapted several times over the years as a result of different Manure Action Programs (MAP). In 2000 manure processing was introduced to reduce the manure surplus. In 2005 Flanders was condemned by Europe for not taking enough effort against nitrate pollution of surface waters. The condemnation led to a new Manure Decree which was introduced in 2007. In 2010 the third action programme (MAP3) ended and again the EC judged that the measures taken were not enough. On the 6th of May 2011 the new Manure Decree was adapted and approved by the Flemish parliament. In 2015 a new Manure Decree (MAP V) is expected to become valid.

The Flemish Manure Decree defines manure processing as:

- Exportation outside the Flemish region of non-processed manure (only poultry/horse) or of other types of manure than poultry or horse, after specific approval by the receiving region or member state
- Exportation outside the Flemish region of processed manure
- Disposition of processed manure on non-farming land (private gardens, parks,…)
- Conversion into a mineral fertilizer
- Conversion to N_2

Who has to process manure?

- Certain farmers belonging to a 'business unit' with manure processing obligation. The manure processing obligation of a business unit in a certain year equals 0.6% for each 1000 kg net N-surplus of that year. This number is augmented by a certain percentage depending on the regional manure production pressure (kg N/ha)
- Every farmer who produces more manure than there is available land in Flanders (this is more than the fraction with manure processing obligation)

The objective of manure processing is to decrease the addition of nitrogen from animal manure and other fertilizers on Flemish arable land.

Anaerobic digestion as such is not considered as a manure processing technique if the digestate returns to Flemish farm land since it still contains all the nutrients originally present in the manure. Only if the digestate is treated in a way that the conditions mentioned above are met, it can be considered as processed.

6.2.3 VLAREM

All activities that can cause nuisance to local neighbours or the environment have to apply for an environmental permit. This is also valid for digestate and manure processing facilities.
Vlarem divides all activities in categories, in order to make a distinction between less and more risk of hindrance. Each category represents an administrative procedure, with specific requirements and conditions.

6.2.4 VLAREMA

In Flanders raw manure and processed manure is not considered to be a waste. However, installations that co-process manure with organic waste are waste processors and for these end-products VLAREMA applies. VLAREMA is the Flemish regulation for materials and wastes. For fertilizers and growing media that are derived from waste, it defines the maximal limits for inorganic and organic contaminants.

7 Economic assessment

7.1 Analysed systems and assumptions

In the economic assessment, conducted by Luxembourg Institute of Science and Technology based on data delivered by the Flemish partners, different existing digestate treatment systems have been analysed. Composting (A) and drying and pelletizing plant (B) treat "stackable substrate" (solid fraction of the digestate) with dry matter content of 26 and 55% respectively. The other three systems deal with raw digestate with dry matter content of 9-11%. These are drying (C), biological treatment, reverse osmosis & drying at a single plant (D) or reverse osmosis and drying pilot plant (E). The analysed treatment systems allow recovering nutrients captured in the following intermediates (with a potential of becoming final products): compost, dried digestate, reverse osmosis (RO) concentrate and an ammonium sulphate $(NH_4)_2SO_4$ solution. Currently for all technologies the intermediates are put together in a final product, which is a mix of ammonia sulphate or RO-concentrate with either compost or dried digestate. The rationale behind this mixing pattern is linked to the current legal and market situation or client demands.

The treatment costs analysis includes three groups of costs (excl. VAT):

- **total investment costs** (buildings, installations, infrastructure, machines and land acquiring),
- **operational costs** (power and heat supply, materials, chemicals, internal transport, machine operating costs)
- **manpower costs** (plant workers)

Each investment was calculated for 20 years and no subsidies or any form of financial support is considered in the analysis. The transport of substrate into the treatment plant was excluded from the calculation.

The sources of energy differ from plant to plant (biogas, natural gas, mixed scenarios, etc.), which makes comparison of the concepts difficult. In order to make the analysis more transparent and transferable, the total electricity and heat demand was assumed to be satisfied by acquiring energy (power & heat) according to its market price for all the studied plants. More details regarding the study can be found in the paper "Assessing the treatment costs and the fertilizing value of the output products in digestate treatment systems" by Golkowska *et al.* (2013).

7.2 Treatment costs, cash flows & fertilizing value

While comparing the total treatment costs (see Table 4) it becomes obvious that, in relation to the input volume, the treatment via composting (6€/tonne input) is much more economical than in the other systems, while the treatment costs for both drying plants B and C (14 €/tonne input) are only slightly lower in comparison to biological treatment, reverse osmosis & drying plant D (16 €/tonne input), even though there is a substantial difference in the input characteristics. It is also important to mention, that the costs of the pre-treatment processes (realized before the substrate was delivered for drying and composting) and energy inputs are unknown and not included in this study (concerning plants A and B). For the reverse osmosis and drying unit E the input based costs reach nearly 38€/tonne input, however this plant runs in pilot scale, treating less volumes and using non-standard technologies.

Table 4: Treatment costs and fertilizing value of the outputs for different systems

Parameter	Unit	A	B	C	D	E
Input based treatment costs	€/tonne input	5.8	14.0	14.0	16.0	37.8
Output based treatment costs	€/tonne output	8.0	19.0	108.8	246.9	215.7
Potential fertilizing and humus value (PFHV)	€/tonne output	21.3	56.5	70.4	51.4	34.7

Since composting and drying plant B deal with stackable inputs with high dry solids content, the volume reduction during the treatment is much smaller than for the other plants treating liquid digestate. Consequently the specific treatment costs for these plants based on the input and output volumes do not differ so much as in comparison to other plants treating raw digestate (C-E). For the latter ones the strong volume reduction during the treatment process results in strongly increased output based treatment costs.

The treatment costs, which arise during the whole operating period, can be divided into costs contributing to the development of the region and those transferred out of the region. The largest part of the cash flow in each investment is linked to energy supply (23-43%). Use of locally produced renewable energy e.g. from biogas instead of fossil fuel based energy can significantly enhance the regional cash flows. In general use of the locally sourced energy and involving local companies in the site construction together with the local manpower can contribute to the local binding of 72-94% of the whole invested capital. This is important information to be considered by potential investors, which can have strong influence on creating local advantages of the treatment systems through local binding of capital and generating safe jobs in the field of green energy.

The potential humus and fertilizing value (PFHV) of the treatment products was calculated based on their content of accountable N, P_2O_5, K_2O and Humus-C as well as the current market prices for these nutrients. The calculated PFHV for the treatment products are compared in Table 4 with the annual specific treatment costs calculated on the product basis. This comparison shows that if the treatment products for plant A and B, dealing with stackable digestate, were to be sold at about 50% of their PFHV), the treatment costs would be completely covered by sale revenues. For plant C, D and E, even if the products would achieve their PFHV, there would still be costs of 0.6-12.6 €/tonne input that would need to be covered either by the digestate suppliers or any form of financial subsidy. For all five scenarios the evaluation does not include any external transport costs (ca. 8.50 €/tonne and 100 km), which either need to be additionally paid by the product end users or included in the treatment costs, which in case of plants treating raw digestate would either lead to increased substrate "disposing" prices or would have to be compensated by higher subsidies for the treatment installations.

Considering current legislation and market situation for digestate treatment products in Europe, the PFHV may be considered a highly theoretical estimation. In practice, the price of digestate treatment products does not only depend on their quality, but also on the application sector (e.g. agriculture, horticulture, landscaping or hobby gardening), volume produced or geographical location (Barth, 2006; Kellner *et al.* 2011). In fact, many treatment plants are forced to give their products away for free, others manage to sell at prices ranging from 2 to 10 €/tonne, while other plants export over longer distances and sell their products for nearly 30 €/tonne (including current transporting costs of ca. 8.50 €/tonne and 100 km).

7.3 Conclusions

Strategic planning of the treatment plant, considering use of the locally sourced energy, may lead to the regional binding of more than 70% of the whole invested capital, contributing to the development of the region by creating safe green jobs in the agricultural sector.

Low demand for products derived from digestate treatment and their extremely low market price are not in accordance with their real fertilizing and humus value. Moreover, in the current market situation, the treatment costs for stackable pre-dried digestate could be covered by selling treatment products even if less than 50% of the fertilizing value were to be returned. Treatment of raw digestate cannot be financed from the output revenues only, even if they would be sold at the market price reflecting the real fertilizing value of their components. Consequently, in the regions, in which, due to nutrient surplus in the agricultural soils, the authorities try to prevent an additional nutrient flow from digestate via digestate treatment (and export), it can be necessary either to financially support the treatment plants or to introduce digestate disposal fees ("bring-in-fees") to assure existence basis for the treatment systems.

8. Environmental assessment

8.1 Aim of the study and analysed systems

The environmental assessment of digestate composting (A), drying and pelletizing (B) and biological treatment, reverse osmosis & drying at a single plat (D), also discussed in chapter 7, together with ammonia stripping of raw digestate (F), considered as interesting future scenario for Flanders, was conducted at Luxembourg Institute of Science at Technology[1]. The main goal of this LCA study was to assess the environmental impacts related to the conversion of digestate from biogas production through different treatment technologies and the subsequent applications of the products on the fields, in comparison to the impacts attributed to direct spreading of digestate on fields. Since the four analysed treatment systems deal with different digestate fractions (raw digestate, solid fraction and pre-treated solid fraction) the direct comparison between the systems was not possible. Consequently, the treatment systems were compared to the baseline scenarios, which for each technology included the same treatment steps of storage, transport and spreading but differed with regard to the digestate characteristics. The simplified chart flows of the analysed processing systems are presented in Figure 1. More details regarding the analysed systems and assumptions can be found in Vázquez-Rowe *et al.* (2015) and Golkowska *et al.* (2015).

8.2 Data and applied methods

The operational inputs and flow streams were relatively well characterized based on the data provided by the plant operators. For representativeness reasons the typical biogas digestate characteristics from Flanders was applied but considering the mass and nutrient balances according to plant operators or extracted from the literature (Bakx, 2009) if the necessary data was not complete. The data linked to the background processes were obtained from the ecoinvent® v2.2 (Frischknecht *et al.*, 2007; Nemecek *et al.*, 2007) database or other literature sources (Amon *et al.*, 2006; De Mol *et al.*, 2003; Deckx and Deboosere, 2005; De Vries *et al.*, 2012; IPCC, 2013; Rehl, 2012). The data were computed using the ReCiPe assessment method (Goedkoop *et al.*, 2009)). Moreover, the impacts linked to toxicity were analysed with the USEtox assessment method (EC, 2010). The analysis included a broad range of impact categories, such as: climate change, ozone depletion, terrestrial acidification, freshwater eutrophication, marine eutrophication, human toxicity, photochemical oxidant formation, particulate matter formation, terrestrial ecotoxicity, freshwater ecotoxicity, marine ecotoxicity, ionising radiation, agricultural land occupation, urban land occupation, natural land transformation, water depletion, metal depletion, fossil depletion.

[1] The environmental analysis for drying (C) and reverse osmosis and drying pilot plant (E) was not possible due to incomplete data inventories

8.3. The main outcomes

Treatment and spreading of the products generate much less environmental emissions than direct spreading of the untreated digestate for BS II and BS III linked treatment processes. Nevertheless, the most beneficial environmental improvements (higher reductions as compared to the baseline scenario) can be achieved in the plants treating raw digestate. In general for all the treatment systems 3 out of 18 analysed impact categories (i.e., climate change, particulate matter formation and fossil depletion) contribute to 95% of the final impact (s. Figure 2).

From an environmental perspective, treatment of digestate through composting brings no significant environmental benefits about as compared to the spreading of untreated digestate. It mainly allows shifting the emissions from the field works in the BS I to the storage, treatment and the air treatment steps (s. Figure 2).

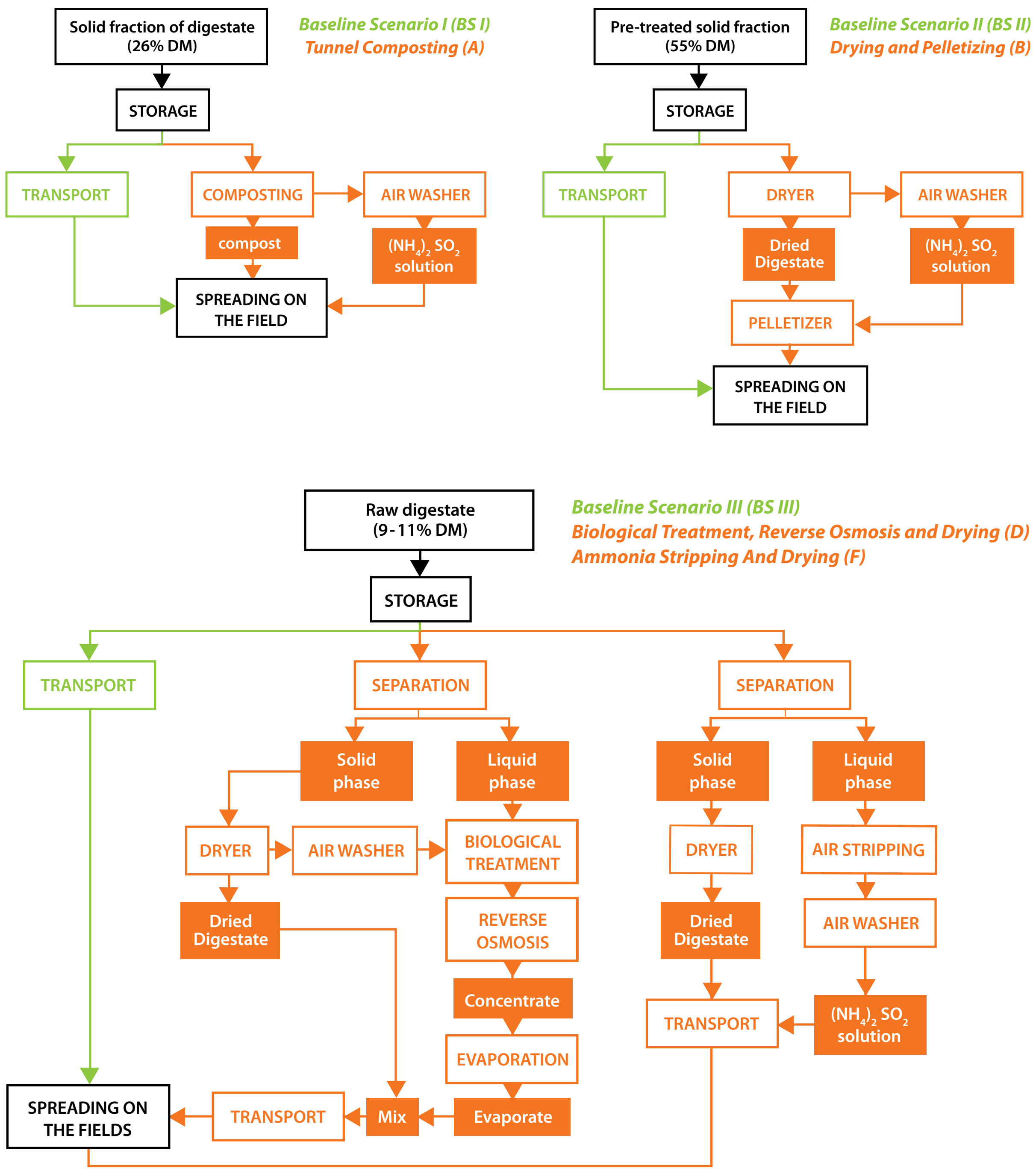

Figure 1: Treatment systems analysed through Life Cycle Assessment including the accompanying baseline scenarios

The treatment of stackable pre-treated digestate by drying & pelletizing allows reducing the total environmental impacts by 35% (s. Figure 2) as compared to the direct spreading (BS II). Although it causes more impacts in 13 categories and allows reducing impacts in 5 categories, the total positive result is mostly influenced by reductions in climate change and particular matter formation. The impacts avoided in these categories are mainly linked to an important reduction in ammonia emissions and are not counterbalanced by the considerable increase in the use of fossil fuels linked to the processing steps.

Overall, treatment of raw digestate allows reducing total environmental impacts for scenarios D and F by 45% and 52% respectively as compared to the baseline scenario III (s. Figure 2). Where it comes to ammonia stripping, the increased use of fossil fuels and materials contributes to higher impacts in all toxicity categories as well as for freshwater eutrophication, ionizing radiation and resources depletion. Nevertheless, a final reduction of the summary indicator, mainly due to significant reductions in particular matter formation and climate change (linked to substantial reductions of ammonia emissions), can be obtained. Also in biological treatment based processing the additional energy demand contributes to the increased impacts in majority of the analysed categories. Here the highest impacts are measured for fossil depletion, ozone depletion and ionising radiation. However, the substantial reduction in particulate matter formation and climate change overweighs all the other impacts and contributes to the significant improvement of the total environmental performance as compared to the direct spreading (SC III). More detailed analysis of the results can be found in Vázquez-Rowe *et al.* (2015) and Golkowska *et al.* (2015).

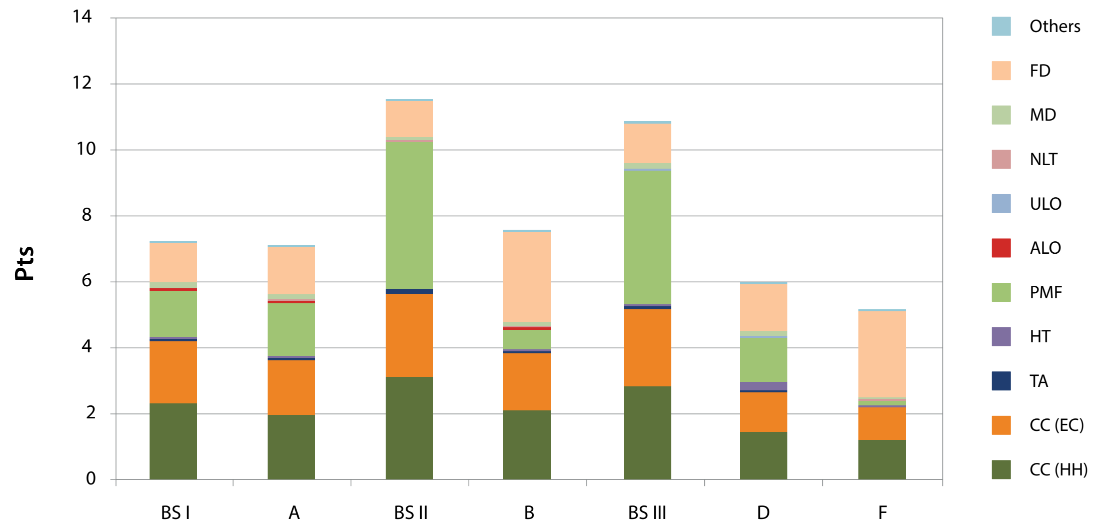

Figure 2: Results of the LCA assessment for the analysed treatment systems and baseline; FD - Fossil depletion, MD - Metal depletion, NLT - Natural land transformation, ULO - Urban land transformation, ALO - Agricultural land transformation, PMF - Particulate matter formation, HT - Human toxicity, TA - Terrestrial acidification, CC(EC) – Climate change ecosystem, CC(HH) – Climate change human health (according to Golkowska et al., 2015)

9. Transferability Questionnaire

9.1 Consumption estimate of manufactured fertilizers

The total mineral fertilizer consumption in the EU-27 amounted to 10.4, 1.0 and 2.2 million tonnes of nitrogen (N), phosphorous (P) and potassium (K) in 2011/2012 (Fertilizers Europe). Table 5 summarizes the consumption of mineral fertilizers in the Benelux, Germany, Ireland and the UK. When focussing on the countries under study, statistics of the period 2000-2008 indicate that the consumption of N and P mineral fertilizers has decreased for all countries under study and most in the Netherlands (N: -4.3%) and Luxemburg (P: about -10%). However when one takes in account the kg of nutrients per hectare of utilised agricultural area the Netherlands report the highest use of mineral fertiliser, closely followed by Belgium, Luxembourg and Germany and Ireland which all have an average mineral fertiliser use of over 100 kg/ha.

Table 5: Overview of mineral fertilizer consumption (ton)

	Phosphorus	Potassium	Nitrogen
Belgium[1]	5 500		143 500
Germany	108 000	320 000	1 640 000
Ireland	22 000	75 000	356 000
Luxembourg[2]	500		15 000
Netherlands	10 000	32 000	233 000
UK	82 000	215 000	1 000 000

Source: Eurostat, 2012, except [1] Eurostat, 2010, [2] Eurostat, 2011

9. Biogas and digestate production

In general 3 major biogas installations types can be distinguished, namely agricultural, sewage sludge and landfill based plants. In Germany and Luxembourg agricultural based plants form the majority in type and energy production, while Belgium and the Netherlands have mixed shares of the different biogas plant types and consequent energy production. Remarkably, the UK and Ireland have a rather high share of biogas plants running on sewage sludge, while the vast majority of biogas production is derived s (s. Figure 3). The respective numbers of digestate production are represented in table 6. However one should be careful to directly link these numbers to valorisation potential.

For the moment 'digestate' is a container concept, with no guarantees towards quality assurance. The quality and composition varies from digester to digester and is strongly dependent on the feedstock. Flanders is one of the strongest in quality assurance, but in other countries this is only poorly elaborated or quasi non-existent.

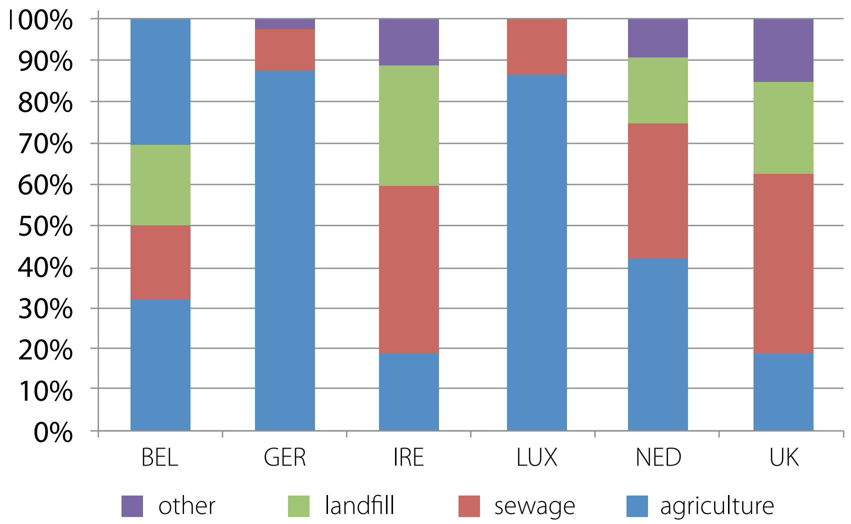

Figure 3: Biogas plants in European countries in 2013 subdivided by type (redrafted from Source: EBA 2014)

Table 6: Annual digestate production (based on total input capacity x 0.9)

		Tonnes of digestate
Belgium	Flanders	2 010 600[1]
	Walloon Region	
Germany		86 250 000
Ireland		unknown
Luxembourg		215 000[2]
Netherlands		
UK		1 400 000[3]

[1] Biogas-E, Voortgangsrapport 2013
[2] ASTA (Administration des services techniques de l'agriculture), 2012
[3] WRAP (2013). A Study of the UK Organics Recycling Industry in 2012. Waste and Resources Action Programme, Banbury, UK.

9.3 What is the current use of the produced digestate?

Digestate is most frequently spread out on agricultural land, as an organic fertiliser for crops, used in the same way as animal slurry, with similar spreading techniques. Similar to slurry, it is sometimes necessary to store the digestate for application at appropriate times (due to the spreading window, spreading is generally not allowed in winter times). In Ireland, Luxembourg, the UK, and also Germany, almost all digestate is spread out on agricultural land. All member states have quality standard protocols for digestate, among other things to ensure it being free from pathogens, chemical and physical contaminants.

However, in some member states, digestate is also further treated. There are 2 main reasons for this. It can either be done to increase the usefulness of the fertiliser itself by separating it into a fibre and solid fraction (as in Ireland), or it can be done in Nitrate Vulnerable Zones (NVZ) with limited field spreading of nitrogen coming from organic manure. In these NVZ, often animal manure field spreading competes with digestate, as they both contain significant amounts of nitrogen from organic origin. As a consequence the nitrogen present in the digestate has to be either converted into an inorganic form, or transported to regions that have a lower abundance of fertilising nutrients locally available. Conversion can be done through denitrification to N_2, or through ammonia stripping and subsequent scrubbing. For long distance transport, digestate is often composted, dried and/or palletised.

Mainly in Flanders, but also in the Netherlands and in some regions in Germany (Lower Saxony, partly Schleswig Holstein and border area of North Rhine Westphalia), digestate is being processed. Techniques used in Flanders are separation, drying, microbiological nitrification/denitrification, ammonia stripping and scrubbing, membrane filtration, composting, … Large amounts of digestate are being exported. The same is valid in the Netherlands, but to a lesser extent. In Germany digestate transfer is mainly executed within the country, as a cooperation amongst federal states. Separation and drying are the most commonly applied techniques in Germany.

9.4 What are the field experiences with the use of digestate and derived products?

Throughout the NWE region digestate is considered as a valuable and attractive fertilisation product. This can be explained by the higher ratio of mineral N to organic N as compared to raw manure which makes the nitrogen more crop available early in the season. Furthermore the organic fractions available in digestate can contribute to the soil organic matter enhancing the soil structure.

More and more farmers have access to digestate and its by-products and there is an increased interest in the benefits and challenge of using these products on the field. In general farmers are satisfied when using these products as they can be easily spread by the existing machinery and the odour emissions are minor to manure application. Drawbacks however are the uncertainty regarding nutrient content as this is highly dependent on the feedstock of the digester and the legal status of digestate (see 9.5).

As digestate is a relative new fertilisation product there are still uncertainties regarding their long term effect on the soil. A specific attention point here is the fear for soil compaction when used in (relatively) wet climates on predominantly medium/heavy soil types (that are poorly drained) (ex. UK and the Netherlands). In several countries there are field trials ongoing in which digestate and its byproducts are compared to classic fertilisation schemes. Flanders and the Netherlands have an extensive number of field trials regarding this topic. For Flanders the results of these tests are elaborated in this report and other field trials can be consulted via the following links:

- http://www.vcm-mestverwerking.be/informationfiles/Bijlage_02_Karakterisatiedigestaten_POVLT.pdf (in Dutch)
- http://www.biorefine.eu/biorefine/downloads

The results for Germany and the UK can be found on respectively www.tll.de – EVA-Project/University of Hohenheim and http://www.wrap.org.uk/dc-agri. In Luxemburg there are also field trials running under the Interreg IVa project ECOBIOGAZ to investigate the fertilizing potential of N captured in raw digestate, solid and liquid fraction of digestate as well as dried digestate in comparison to commercially available mineral N fertilizers. Additionally, long term influences on the soil quality will be investigated. More detailed information can be found via the following links:

- http://www.ecobiogaz.eu/nos-4-actions/nouvelles-recherches-en-aval/ (in French)
- http://www.ecobiogaz.eu/nos-4-actions/promotion-sous-produits/

9.5 How does the status of digestate relate to animal manure at national/regional level?

In Flanders, Ireland and the UK digestate coming from a digester that takes in manure is considered 100% animal manure. In Nitrate Vulnerable Zones, this means a limit of 170 kg N/ha. However, if no livestock slurry is included, the resulting digestate has another status (called differently in the different member states), which allows appliance over the 170 kg N/ha limit, but is still subject to field spreading rate limits (e.g. 250 kg N/ha).

The Netherlands account for total N in digestate as animal manure if at least 50% of the input material is livestock manure and the co-material is part of a specific list.

According to the German Düngeverordnung the limit of 170 kg N/ha is not eligible for digestate, if the input material is not defined as "Wirtschaftsdünger". Currently energy crops are not "Wirtschaftsdünger". According to the planned amendment of the German Düngeverordnung in 2014, it is expected that also digestates deriving solely from energy crops will become subject to the N limitations of 170 kg N/ha. If digestate comes from a mixture of manure and energy crops only the amount of nutrients coming from manure are taken into account for the 170 kg N/ha limit. This will be changed by the amendment of the Düngeverordnung 2014, and the total nutrient amount in the digestate will be accounted for.

In Luxembourg all digestate, independent if animal manure has entered the plant or not, is considered as an "organic fertiliser", and has to be spread out at a maximum rate of 170 kg of N/ha.

9.6 Are there any subsidies for treating digestate?

In none of the member states there are direct subsidies for treating digestate. However, in some of them, the subsidies for renewable energy are directly linked to digestate treatment. In Germany for example, a requirement for the remuneration of renewable energy production from digesting organic waste is that it is necessary to apply a post-rotting after the digestion process.

In Flanders, cogeneration units at anaerobic digestion plants are subsidised, only if the produced heat is used in an efficient way. Drying digestate with this heat is recognised as "an efficient way to use the produced heat." However, in Luxembourg for example the use of waste heat from biogas plants for drying of digestate is not eligible for waste heat use bonus for commercialised heat.

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