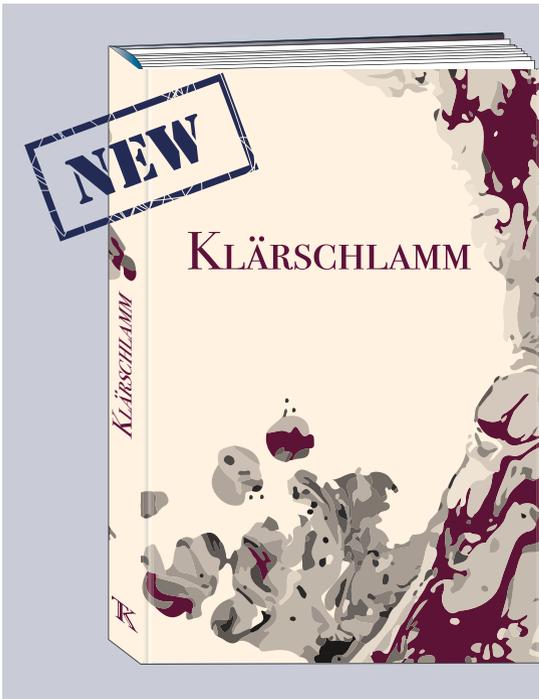


Sewage Sludge



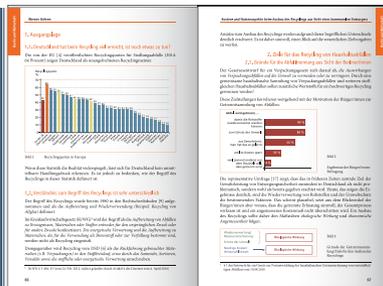
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Due to recent alterations in the legal framework in Germany, the market for utilisation of sewage sludge will be fundamentally changing in the near future. On the one, hand the application in agriculture as fertiliser will be largely restricted. On the other hand, the political will to strengthen the circular economy will be provided. Regarding the sewage sludge the focus lies on the recovery of phosphorous, which is due to the European Commission designated as a critical raw material since 2014.

Numerous procedural approaches considering the recovery of phosphorous from primary sludge or from the residues of thermal treatment exist but with different development status. Against the background of a manifold industrial sector regarding the specification (dimension, stages of treatment steps) and the periphery (urban, rural, local options for utilization) of the sewage plants, many operators seek for meaningful technical solutions and economic concepts. The book will be released accompanied to the "Berliner Klärschlammkonferenz" (Berlin Sewage Sludge Conference) in November 2018 and will give a review to the altered legal framework as well as to innovative procedures and experiences in practice.



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Treatment of Sewage Sludge in Europe: Status Quo and Perspectives of Energy and Phosphorus Recovery

– Illustrated by the Example of Selected Countries –

Martin Gutjahr and Johannes Müller-Schaper

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The regional differences in the amount of sewage sludge produced, and the processes used for recycling vary greatly in Europe. There is a current decline in the acceptance of sewage sludge as fertiliser for agriculture in Central and Northern Europe, and due to the legal requirements specific to each country, this practice is expected to be phased out extensively in the shorter or medium term. The co-incineration of sewage sludge in waste incineration plants, coal-fired power plants and cement works can only be regarded as a temporary solution since phosphorus, an important resource for the future, is lost in the process. Mono-incineration of sewage sludge with the option of recovering phosphorus from the ash therefore presents the most appropriate solution in Central and Northern Europe, both from the technical and the ecological aspect.

On the other hand, the use of sewage sludge in Southern and Eastern Europe for agricultural purposes is regarded as justifiable, at least for the time being, provided the sewage sludge is used as fertiliser in strict compliance with regulations, and provided the corresponding level of pollutant concentrations can be guaranteed to be low. The percentage of households connected to sewage treatment plants as well as the technical development of such plants in Southeastern Europe are in part considerably below the level in Central Europe, and the amount of sewage sludge produced as a result is significantly lower.

It must be noted that the major disadvantage of mono-incineration is the higher specific costs involved with smaller plants. There is a significant potential for the optimisation of the energy output of sewage sludge incineration plants, primarily where larger plants are concerned and when used in combination with solar-powered dryers.

With regard to the recycling of phosphorus, the cost-efficient recovery of phosphoric acid from ash resulting from the incineration of sewage sludge can be expected to be feasible on an industrial scale within a few years.

1. Introduction

In Europe there are several varying methods of treating and utilising sewage sludge. While the emphasis used to be on the agricultural use and landfilling, thermal processes with the option of phosphorus recycling and energy recovery are predominant nowadays. This report serves to give an overview of the current situation in Europe, and a description of processes suitable for the treatment of sewage sludge. In addition to the European overview, the situation in selected countries will be dealt with in more specific detail. The report will illustrate the prospects existing for the recovery of energy and recycling of phosphorus.

2. Legal parameters

The treatment of waste-water in sewage plants is regulated by the European directive 91/271/EEC pertaining to the treatment of urban waste-water. After implementation of this directive, there was a significant increase in the production of sewage sludge in Europe.

Utilisation of sewage sludge in Europe is governed by the directive 86/278/EEC of 1986. The purpose of this is to ensure that the quality of soil, surface and groundwater is retained when sewage sludge is used as a fertiliser, so as not to endanger the environment or human health. To this end, statutory limits are set for heavy metals and the use as fertiliser is restricted. The quantities and the periods for spreading are restricted for areas that are used for grazing or growing fruit and vegetables. The European Commission leaves it to the discretion of the Member States to decide whether to turn this directive into more stringent legislation or to fully approve of the use as fertiliser under certain circumstances.

Incineration or co-incineration is governed by the *Directive 2010/75/EU on industrial emissions*. This directive applies to every type of waste and defines the parameters, the waste heat recovery and the emission limits.

The disposal of sewage sludge in landfills is subject to the directive 1999/31/EC of 1999 on landfill of waste in the European Union. The resulting ban prohibiting the landfill of waste with an organic content of more than 5 % has been in force since July 2009. It is applicable to sewage sludge and has led to a sharp decline in landfilling.

Below is a brief description of the legal situation in Austria, Germany, the Netherlands and Switzerland. It goes above and beyond the European legislation and serves as an example:

- Austria: The regulations for the agricultural use in Austria are left to the discretion of the federal states. In the state of Tirol, Salzburg and Vienna, this type of utilisation is prohibited, while in all other federal states it is allowed, with restrictions to the times and quantities used and on the admissible pollutant content. The incineration of sewage sludge is governed by the Waste Incineration Ordinance while the disposal of residues in landfills is subject to the Landfill Ordinance.
- Germany: In Germany, the new sewage sludge ordinance (AbfKlärV) has been in force since 2017. This ordinance prohibits the use of sewage sludge for agricultural purposes from all sewage treatment plants with a population equivalent (PE) of more than 100,000, making the recovery of phosphorus obligatory, from the year 2029 onwards. From 2034, this ordinance is to apply for sewage treatment plants with a PE of more than 50,000.
- The Netherlands: The targets here are stipulated in the *National Waste Management Plan*. Agricultural use is prohibited and 100 % incineration is aimed for. Preference is given to co-incineration in cement works and mono-incineration.
- Switzerland: The use of sewage sludge for agricultural purposes has been forbidden here since 2003. After a transitional period, the sewage sludge is either incinerated or co-incinerated. The legal basis for this is founded in various laws.

3. Methods of utilising sewage sludge

3.1. Agricultural utilisation

The nitrogen and phosphorus constituents of sewage sludge can be largely utilised as a fertiliser by stabilising and mechanically dewatering the material. This land-based utilisation of sewage sludge is the subject of much controversy. The main advantages and disadvantages are summarised in Table 1.

Table 1: Assessment of land-based utilisation of sewage sludge

Advantages	Disadvantages
Good supplier of nutrients, especially phosphorus	Hazard of over-fertilisation and leaching of nutrients; phosphorus availability to plants subject to pre-treatment
Favourable for the formation of humus as there is a high content of organic matter in sewage sludge	Negative effects of sewage sludge on soil and ground-water (endocrine substances, accumulation of heavy-metals, pathogens, etc.); not all pollutants are regulated by law and can be measured in practice
Concentrations of heavy metals are in part less than those in commercial fertilisers	

A direct correlation between the application of sewage sludge as fertiliser and the health impairment of the consumer could not be determined so far, at least with sewage sludge low in harmful substances and applied correctly during the appropriate seasons. However, by way of precaution, the agricultural use of sewage sludge is being ruled out as a long-term solution in an increasing number of countries.

3.2. Landfilling of sewage sludge

For the sake of completeness, mention must be made of sewage sludge disposal in landfills. This is no longer permissible following the EU landfill ban (Chapter 2). It is greatly declining in Europe, although it is still practised in a few countries (Figure 4, Chapter 4.2). Apart from hygienic concerns, the accumulation of pollutants and the loss of nutrients via leaching all add up to the main arguments against this method of disposal.

3.3. Co-incineration of sewage sludge

The co-incineration of sewage sludge in coal-fired power plants, incineration plants and cement works has become technically established as an option for utilisation. Especially when used in coal-fired plants and cement works, the amount of fossil fuels could be saved to a certain degree. The extent of the utilisation of sewage sludge is dictated by its water content, the sludge drying facilities at the power plant and the admissible concentrations of pollutants in the flue gas.

In Germany, a co-incineration percentage of 5 % of the total fuel mass has proved to be technically feasible in coal-fired plants; in waste incineration plants, this figure can be up to 20 % if the fuel is thoroughly mixed.

The main arguments against co-incineration are as follows:

- The proposed reduction of CO₂ emissions in Central Europe is currently resulting in a rapid shift in the electricity generation by coal to cleaner sources of energy. Coal-fired power plants can therefore not be regarded as a long-term option for utilising sewage sludge, at least not in Central Europe.
- In the process of co-incineration, the phosphorus in the sewage sludge is lost as a rule. In cement works, it becomes irreversibly trapped in the product, and in waste incineration plants, it is mixed with heavily contaminated ash. In coal-fired power plants, trials are being carried out to recover the phosphorus from the ash. However, these trials are still in the pilot phase and they are affected by the declining coal-based power plants.
- The process of co-incineration establishes an economic interdependence between different parties which otherwise operate independently. This involves more risks and can potentially have an adverse impact on the long-term planning.
- The transport of sewage sludge to the co-incineration plants is logistically complex and has a corresponding impact on the environment.

Summarising, it can be said that the co-incineration of sewage sludge cannot be regarded as a suitable method of utilisation in the long-term, primarily because of the loss of phosphorus.

3.4. Mono-incineration of sewage sludge

Mono-incineration of sewage sludge proves to be a technically established and a safe method of utilisation. Its main advantages are listed below:

- Organic compounds such as pathogens and endocrine substances are destroyed completely.
- Pollutants (heavy metals and inorganic compounds) are separated and discharged.
- More than 90 % of the phosphorus contained in the sewage sludge can be recycled from the ash.
- The amount of energy contained in the sewage sludge can be used to a certain extent to generate district heat and electricity.
- The odour nuisance as experienced in the agricultural use can be avoided.

The main disadvantage of mono-incinerating sewage sludge lies in the comparatively high costs. Particularly with relatively small plants having a throughput of less than 20,000 Mg_{TSS}/a (Total Solids), the investment and running costs per unit mass of sewage sludge are higher than for larger plants.

3.5. Comparison of utilisation methods

The following Table 2 summarises the advantages and disadvantages of the methods of utilisation presented here.

Table 2: Comparison of utilisation methods

	Advantages	Disadvantages
Co-incineration in coal-fired plants, cement works, waste incineration plants	<ul style="list-style-type: none"> • Destruction of organic substances • Recovery of energy possible • Cost-effective means of disposal 	<ul style="list-style-type: none"> • Extraction of nutrients and P-recovery from ash not possible • Environmental impact with long transport distances • Uncertainty regarding development of capacities
Mono-incineration	<ul style="list-style-type: none"> • An amount of more than 90 % phosphorus remains in the ash. Ash can be stored temporarily until P-recycling is possible. • High planning reliability for the operator of the sewage treatment plant. • Complete destruction or discharge of pollutants • Recovery of energy possible 	<ul style="list-style-type: none"> • High costs • P-recovery not established on an industrial scale • Long periods of implementation • Centralised plants mean correspondingly high logistic costs in less densely populated areas
Agricultural use	<ul style="list-style-type: none"> • Recovery of nutrients, especially phosphorus • Very cost-effective means of utilisation 	<ul style="list-style-type: none"> • Pollutant contents constitute a risk for soil and groundwater • Problems of acceptance, odour • Central Europe: Low planning reliability in view of changing legal parameters • Seasonal fluctuations in production and demand necessitate temporary storage

This summary shows that mono-incineration of sewage sludge in conjunction with phosphorus recycling can be regarded as the best technology currently available for sewage sludge utilisation.

4. Current treatment methods of sewage sludge in Europe

Generally, it must be admitted that data acquisition in Europe concerning the utilisation of sewage sludge varies greatly. There are loopholes, contradictions and there is no universally accepted method of acquisition. Comparability of data is limited to a certain extent, which means that conclusions and recommendations cannot always be verified in detail.

4.1. Sewage sludge production

The amount of sewage sludge produced per annum and per person also varies greatly from country to country in the European Union. Figure 1 shows the specific figures for households that are connected to a sewage treatment plant.

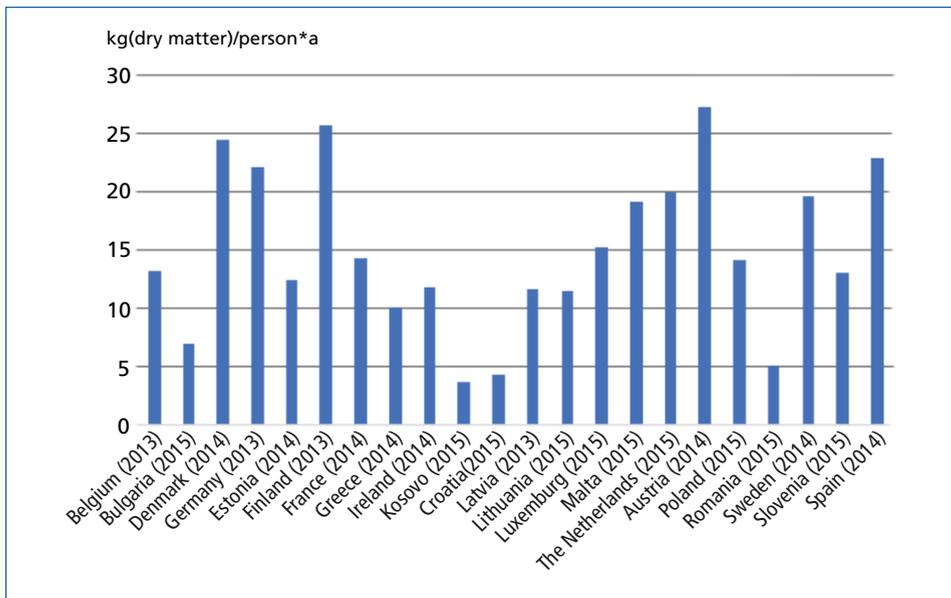


Figure 1: Sewage sludge produced in kg per person, where households are connected to a sewage treatment plant

Source: Eurostat: Gesamtklärschlammaufkommen und Behandlung aus öffentlicher Abwasserbehandlung. August 11, 2016 [Online]. Available: <http://ec.europa.eu/eurostat/tgm/refreshTableAction.do?tab=table&plugin=1&pcode=ten00030&language=de>. [Accessed June 25, 2018].

In Figure 1, a certain positive relation can be seen between the economic development of a country and the specific amount of dry matter (DM). This correlation cannot be explained by the difference in the extent of technical equipment used in the sewage plants. The more modern sewage plants have digestion phases that signify smaller

specific amounts of dry matter. It is rather assumed that the vague nature of data acquisition is responsible for these differences. There is no uniform standard for such data acquisition across Europe.

By looking at the percentage of households connected, we can draw conclusions about the magnitude of sewage sludge generated in the respective countries. If the percentage is high, then a stable amount of sewage sludge can be expected to be produced annually. If the percentage is low, then the annual amount of sludge produced can be expected to rise considerably due to an increase in the number of households to be connected in the future. This in turn means that the concepts for sewage sludge recycling must also be adapted.

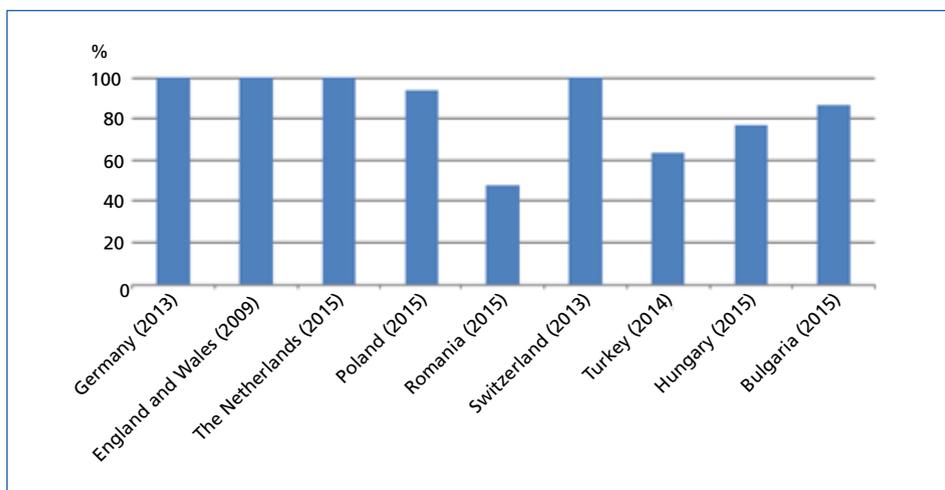


Figure 2: Percentage of households connected to sewage treatment plants in Europe

Source: Eurostat: Eurostat: Anschlussgrad der Bevölkerung an Abwassersammlung und -behandlung. August 11, 2016 [Online]. Available: <http://ec.europa.eu/eurostat/tgm/table.do?tab=table&init=1&language=de&pcode=tgs00110&plugin=1>. [Accessed June 26, 2018].

As can be seen in Figure 2, the percentage of households connected to sewage treatment plants is 100 % in most of the countries considered, while some countries in Southeastern and Eastern Europe are lagging behind. It must be considered here that the expenditure for connecting all households to a sewage treatment plant is very high in rural areas with a less dense population. The options for planning a comprehensive concept for sewage plants and sewage sludge recycling facilities are diverse.

4.2. Overview of current methods of sewage sludge utilisation

The most suitable process for utilisation of sewage sludge cannot be selected regardless of the regional parameters that differ from country to country. Relevant factors include population density, agricultural practices, climatic conditions, soil quality and economic parameters. The following description outlines these specific factors, with reference to a selected number of regions/countries.

Central Europe

In consideration of the much controversial debate surrounding the occurrence of pollutants, the utilisation of sewage sludge for agricultural purposes will be cut back significantly or will be restricted even further or prohibited by statutory provisions. Moreover, the problem of overuse of fertilisers in certain areas forces us to consider options for disposing the sewage sludge elsewhere. This is particularly relevant in areas where there is intensive livestock farming. Manure and substrates from bio-digesters are used as fertiliser here, which means that sewage sludge cannot be used in addition.

In Germany, now that legislation has come into effect (Chapter 2), the mono-incineration of sewage sludge is playing an increasingly significant role. Plans are currently being made for a large number of sewage sludge incineration plants. In Switzerland, The Netherlands and parts of Austria, the agricultural use of sewage sludge has already been banned.

Eastern Europe

As more and more households are now being connected to sewage treatment plants, a greater amount of sewage sludge can be expected as a consequence. In addition to the use in agriculture, which has been the preferred method of disposal so far, consideration must also be given to other options of disposal or utilisation. One attractive alternative would be co-incineration in waste incineration plants. However, amid scepticism from the population, combined with bureaucratic obstacles, there may be delays in developing co-incineration.

Southeastern Europe

Here, too, the increasing number of sewage treatment plants as well as the increasing percentage of households connected to such plants leads to a rise in quantities of sewage sludge produced. Phasing-out of agricultural utilisation is expected for the most part, so that the options of co-incineration and mono-incineration are likewise attractive solutions for the disposal of sewage sludge. On the other hand, the demand for sewage sludge as a fertiliser remains high since the soil has very low humus content in parts, thus giving rise to acidification and erosion. Consequently, there are great efforts to treat the sewage sludge so that the valuable substances can be extracted, while minimizing the amount of pollutants simultaneously.

Figure 3 and Figure 4 illustrate a marked change towards a significantly greater utilisation of sewage sludge incineration.

However, the utilisation of sewage sludge still varies greatly from country to country. Some of the reasons for this have been explained above. This can be examined more closely by looking at the methods of utilisation employed by individual countries.

Figure 4 shows that landfilling still represents the major portion of sewage sludge disposal in some countries, despite the EU ban. Certain parallels can be drawn here with the development of landfilling and incineration of domestic waste.

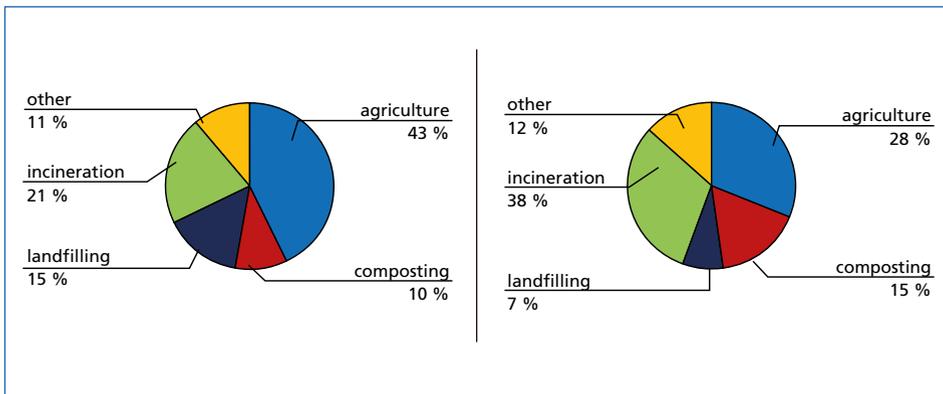


Figure 3: Sludge disposal methods in the EU in 2015 (left) and 2005 (right)

Source: Eurostat: Eurostat: Gesamtklärschlammaufkommen und Behandlung aus öffentlicher Abwasserbehandlung. August 11, 2016 [Online]. Available: <http://ec.europa.eu/eurostat/tgm/refreshTableAction.do?tab=table&plugin=1&pcode=ten00030&language=de>. [Accessed June 25, 2018].

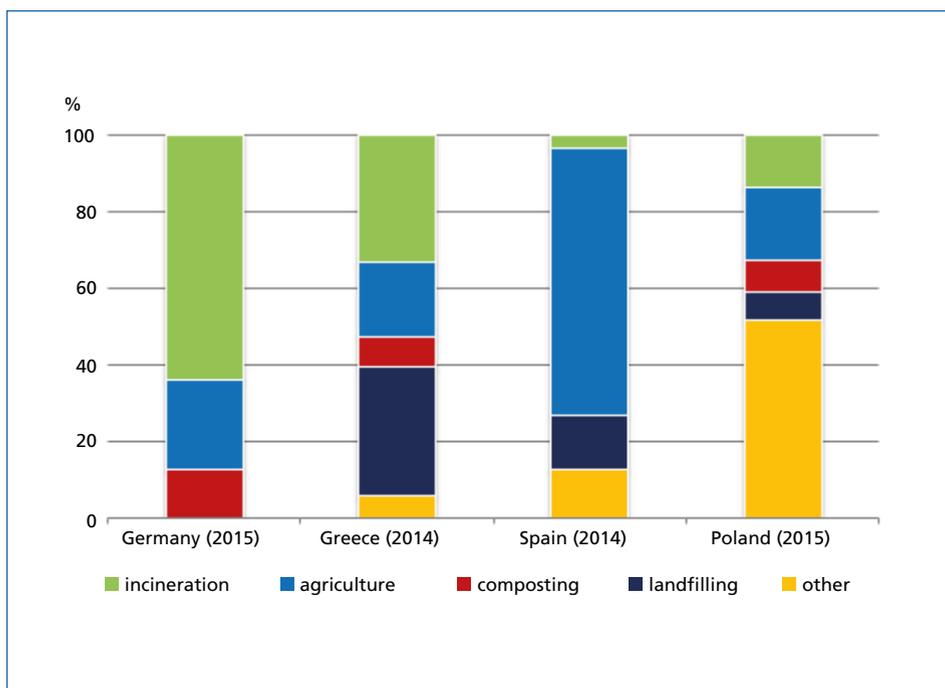


Figure 4: Sewage sludge utilisation in selected countries

Source: Eurostat: Eurostat: Gesamtklärschlammaufkommen und Behandlung aus öffentlicher Abwasserbehandlung. August 11, 2016 [Online]. Available: <http://ec.europa.eu/eurostat/tgm/refreshTableAction.do?tab=table&plugin=1&pcode=ten00030&language=de>. [Accessed June 25, 2018].

5. Prospects of energy and phosphorus recovery

5.1. Recovery of energy

The co-incineration of sewage sludge in coal-fired power plants and cement works can be very effective from an energetic point of view, especially when heat is used to dry the mechanically dewatered sludge. However, these processes do not appear to be sustainable in the future because of the lack of P-recycling, amongst other things. Therefore, with a view to optimizing the recovery of energy, prime consideration should be given to the option of mono-incineration.

With regard to the recovery of energy from sewage sludge, it is often argued that the composition of the dry residue of sewage sludge being comparable to that of lignite, the same extent of the recovery of energy should be achieved or at least aimed for. This comparison is however not quite correct, for the following reasons:

- Even after the mechanical dewatering, sewage sludge still contains approximately 70 to 80 % water. To further reduce the water content to approximately 60 % so as to enable self-sustaining incineration, it would need to be dried further by heating. The calorific value of mechanically dewatered sewage sludge is only approximately 1 to 2 MJ/kg, while that of raw lignite is 8 MJ/kg.
- Sewage sludge incineration plants are very small in comparison with lignite-fired power plants; the thermal output is a single-digit percentage compared to the conventional coal-based power plants. This implies that only smaller turbines can be used which have lower efficiencies. Besides, if a back-pressure turbine is employed, which is usually the case, the captive consumption of heat for the drying of sludge comes at the cost of a lowered gross electrical output. The following diagram is based on the actual recorded energy flows of an incineration plant with a throughput of 18,000 Mg_{DM} in the respective year.

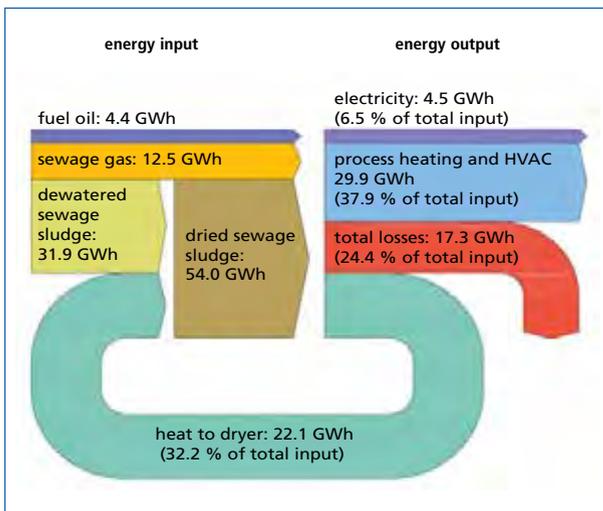


Figure 5:

Energy flows of an existing sewage sludge incineration plant with a throughput of 18,000 Mg_{DM}/a

However, optimization of energy is still possible, even with sewage sludge incineration plants. Here are some examples:

- By mixing mechanically dewatered sludge with solar dried sludge, incineration of sludge may be possible without drying. Solar powered dryers have meanwhile become state of the art technology and they can provide an economic means of drying in combination with sewage sludge incineration plants. But storage of solar dried sludge and mixing still represent a technological challenge.
- Excess heat can be used for generating district heat or for heat consumers in the sewage treatment plant, such as the digesters.
- By optimizing the turbine and steam parameters in larger sewage sludge incineration plants, it is in fact possible to increase the efficiency to a certain degree. Unlike in waste incineration, the steam parameters are not limited by high-temperature chlorine corrosion in sewage sludge incineration plants.

The following graph shows the energy balance of a typical sewage sludge incineration plant with an annual throughput of 40,000 Mg_{DM} for two cases:

1. Use of mechanically dewatered sewage sludge with 25 % DM
2. Use of mechanically dewatered sewage sludge, mixed with dried sewage sludge with 70 % DM; corresponding ratio of approximately 67 % mechanically dewatered sludge to 33 % dried sewage sludge, which results in 40 % DM of the mixture

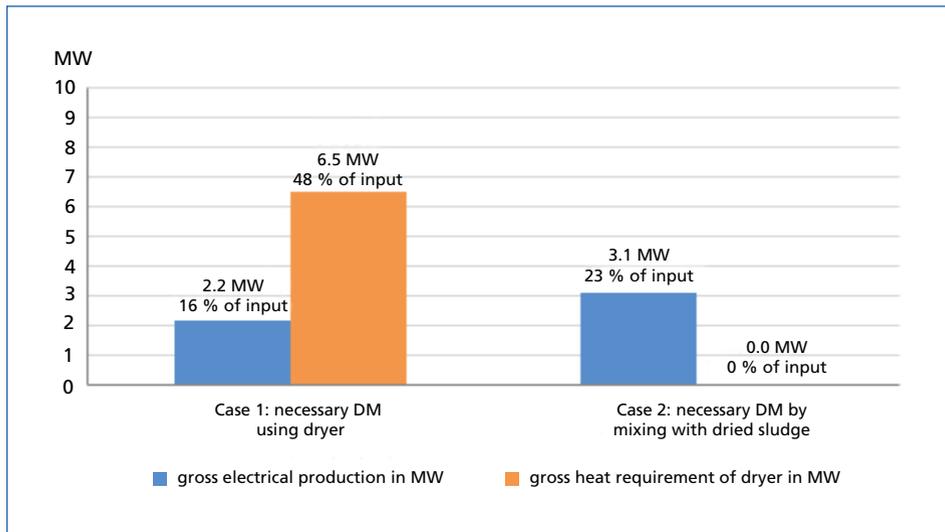


Figure 6: Comparison of energy output of sewage sludge incineration with dryer and with mixture of dried sludge

By omitting the drying process of sewage sludge, it is possible to use a condensing turbine. This is in turn favourable for the generation of electricity. The electrical output could be increased by approximately 40 % by this mode of operation.

However, the drawback with the solar dryer combination is that seasonal fluctuations in the dryness fraction are inevitable, at least in Central and Northern Europe. But this combination would appear to be particularly interesting for countries in the south.

5.2. Recycling of phosphorus

Since the natural reserves of phosphorus are limited, and due to the diminishing quality and the difficult extractability, the costs of phosphorus mining are on the increase. It will therefore be economical and expedient in the future to recover phosphorus from sewage sludge.

Numerous processes with varying stages of development have been developed for the recovery of phosphorus. The main criteria and differences of these processes are to be found in the plant availability of the phosphorus compounds, as well as in the investment and running costs.

A clear overview of these processes can be found in publication [10]. Summarising, the following insights have been gained:

- The recovery of phosphorus from waste water or sewage sludge is possible, but the recovery rate is less than 50 %. These processes are economically viable only under certain conditions such as improved dewatering characteristics of the sewage sludge.
- The recovery potential of phosphorus from the ash is around 90 %. Apart from the direct recycling of ash, the downstream treatment processes that reduce the concentration of the pollutants and enhance the availability of ingredients for plants have garnered more interest. Some of the available methods have already proven their suitability in pilot recovery plants.
- For the recovery of phosphorus from ash, the most economic process would appear to be the production of phosphoric acid in large centralised plants [10]. Reference is made here to the Ecophos fertiliser factory that is due to commence operation in Dunkirk in 2019 and which is to recycle primarily ash from the sewage sludge incineration plants in Dordrecht and Moerdijk. Moreover, the TetraPhos-process of the company Remondis has to be mentioned. Currently, industrial scale trials are being carried out in Hamburg.

This overview is by no means complete. There are signs that state of the art technology will be achieved in the medium-term for the recovery of phosphorus from sewage sludge ash. But this remains to be verified on an industrial scale. Until then, the ash needs to be put in temporary storage. It can then be used appropriately in centralised plants later on.

6. Conclusion and recommendation

This overview shows that there are great regional differences in the amount of sewage sludge produced and the processes used for its utilisation. While the mono-incineration of sewage sludge will become the *gold standard* for utilising the sewage sludge in Central and Northern Europe in the short and medium-term, the situation in Southern and

Eastern Europe is not quite so clear. Here, the use of sewage sludge for agricultural purposes is regarded as a temporarily acceptable solution, provided an adverse impact on the environment can be excluded as far as possible.

Moreover, the percentage and the technical development of sewage plants connected to households in Southeastern Europe are in part well below the level in Central Europe. However, an increased generation of the sludge needs to be certainly accounted for in the future.

Generally, when planning and constructing new large sewage treatment plants, it is expedient to thoroughly examine the possibility of combining them with a sewage sludge incineration plant to leverage the synergy effects as far as possible. The envisaged plant in Podgorica (Montenegro) serves as an excellent example.

As a further comment, it would seem appropriate to mention that large quantities of untreated domestic and similar waste are still being dumped in landfills in Europe. For ecological concerns, prioritisation would seem appropriate where funds are limited. Firstly, waste-to-energy plants should be built for domestic and industrial waste, to be followed by incineration plants for sewage sludge.

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