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Policy Brief

Sustainable disposal and use of sludge-based biomasses

SUSTAINABLE BIOGAS

Photo: Vladvitek, Dreamstime.com

Summary

No sewage sludge management option is optimal from all important societal perspectives, including pollution prevention, maximised nutrient recycling and minimised GHG emissions.

Solutions contributing towards achieving the above-mentioned objectives include:

- Phosphorus recovery from wastewater and nitrogen recovery from reject water, which contribute to nutrient recycling without increasing the risk of soil pollution by harmful substances in sewage sludge.
- Energy recovery from sewage sludge e.g. by digestion or pyrolysis, and replacement of mineral phosphorus fertilisers with recycled fertilisers. This both mitigates climate change and advances the circular economy but does not completely eliminate the circulation of harmful substances.

Policymakers, authorities and other stakeholders should definitely continue the reconciliation of objectives and support research into technical solutions for the sustainable disposal and use of sludge-based biomasses.

Introduction

Sewage sludge is the residual material from wastewater treatment. The treatment and utilisation of sewage sludge has been the subject of much debate in recent years. There are many different aspects involved including: the disposal of sludge-based biomasses treated in different ways, the utilisation of the energy and nutrient content of the sludge, health and environmental impacts, logistical issues, cost implications and brand image issues of companies.

Currently, most of the sludge is utilised in agriculture and landscaping after treatment in ways such as anaerobic digestion and/or composting (in Finland) and storage or composting (in Latvia). However, the agricultural use of sewage-based biomasses may become more difficult in the coming decades as EU legislation[1] is changing. In addition, some market related barriers already exist as some large European food industry companies have prohibited the use of grains fertilised with sludge-based biomasses in their products.

This context motivates the analysis of alternative technological routes for sludge-based nutrient management and the search for opportunities that improve current practices.

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[1] Urban wastewater treatment directive (91/271/EEC) and sewage sludge directive (86/278/EEC).

Analysis

The pros and cons of various sludge management options were studied by the Finnish Consulting Group. In a report[2] prepared for the project 'Sustainable Biogas', the following technological options were included:

- Biogas production at a wastewater treatment plant (WWTP)
- Sludge incineration
- Co-digestion outside the WWTP and nutrient recovery
- Thermo-chemical treatment of sludge **(Box 1)**

Compared to the first option, the following three technological options involve sewage sludge treatment in larger units and longer transport distances.

Each sludge management option was studied against five criteria reflecting the environmental and economic sustainability of the treatment options **(Box 2)**. These included:

- Cost minimisation
- Pollution prevention
- Material reduction
- Climate change mitigation
- Contribution to the circular economy

The impact analysis was made using calculation methods (mass balances, costs and carbon footprinting), data from a literature survey and an expert evaluation.

BOX 1. ANALYSED SLUDGE MANAGEMENT OPTIONS

Biogas at WWTP involves sewage sludge thickening, anaerobic digestion, dewatering of digestate, composting and refining/ sieving. The process generates biogas (that can be utilised in the WWTP to generate heat and electricity, or heat only), a soil improver for agriculture or landscaping, and screening residues.

Incineration involves sewage sludge thickening, dewatering, transportation to a combustion plant, drying and combustion. Produced energy can be utilised as heat and electricity, or heat only. In addition, solid wastes such as fly and bottom ash are generated. In some cases, fly ash can be further processed for phosphorus recovery.

Co-digestion outside the WWTP involves sewage sludge thickening, dewatering, and transportation to a combined biogas and thermal drying plant, with the idea of anaerobic digestion and further nutrient recovery (nitrogen stripping from reject waters and production of soil conditioner granules). Biogas can be utilised in the plant or used either as heat and electricity, or just heat, or liquefied biogas (LBG) can be produced. Screening residues are treated or disposed of.

Thermo-chemical sludge treatment (in this study: pyrolysis) involves sewage sludge thickening, anaerobic digestion, dewatering of digestate, transportation to a thermo-chemical plant, thermal drying, and thermolysis. Biogas from anaerobic digestion and energy from the thermo-chemical treatment process can be utilised to generate heat and electricity, or heat only. Moreover, hydrocarbons for the (petro)chemical industry and biochar for soil improvement can be produced.

BOX 2. EXPLANATION OF CRITERIA

Cost minimisation: Economic impact, i.e. yearly net costs are calculated as the sum of investments costs (assuming a 20-year depreciation period and 3% interest rate), operating costs and revenues from products of the sludge treatment processes

Pollution prevention: Removal of harmful substances from circulation

Material reduction: Total solids after the sludge treatment processes

Climate change mitigation: Carbon footprint, i.e. direct and indirect GHG emissions and emission offsets of the sludge treatment processes

Contribution to the circular economy

- N recovery: nitrogen in the outputs of the sludge treatment processes
- P recovery: phosphorus in the outputs of the sludge treatment processes
- C recovery: potential to increase the organic matter content of soils

Results

The main strengths of **biogas production at a WWTP** lie in cost minimisation and contribution to the circular economy. The weaknesses are mainly related to pollution prevention and a higher carbon footprint compared to sludge incineration or thermo-chemical sludge treatment. The carbon footprint is, however, lower than in sludge composting without energy recovery.

Sludge incineration is beneficial from the perspectives of cost minimisation, pollution prevention and material reduction. It enables energy recovery from sludge, but it does not enable nutrient recycling without additional technologies.

The selected process example for sludge **co-digestion and further nutrient recovery** scores well in terms of contributing to the circular economy, but is less optimal in pollution prevention, climate change mitigation and cost minimisation.

Pyrolysis is ideal from the perspectives of climate change mitigation, pollution prevention and N recovery. It is somewhat weaker in terms of cost minimisation and P recovery.

BOX 3.

New technologies[3] can enhance nutrient recovery from wastewater, sludge or ashes. For further information on the impact of selected technologies (RAVITA, ASH DEC and Stuttgart process for struvite recovery) on the ranking of sludge management options, see the full report at *https://tinyurl.com/sewagesludge*.

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[2] See report '*Sustainable future usage or disposal possibilities of sewage sludge-based biomasses in Finland*'.

[3] See e.g. Global Compendium on Phosphorus Recovery from Sewage/Sludge/Ash (*https://www.vesiyhdistys.fi/wp-content/uploads/2019/12/GWRCPhosphorusCompendiumFinalReport2019-March-20.pdf*) and Catalogue of phosphorus recovery technologies (*https://phosphorusplatform.eu/images/download/ESPP-NNP-DPP_P-recovery_tech_catalogue_v26_4_22.pdf*).

COMPARISON OF SLUDGE MANAGEMENT OPTIONS

	BAU Biogas at WWTP	1 Incineration	2 Co-digestion + nutrient recovery	3 Thermo-chemical treatment
Cost minimisation Compared to BAU, the cost difference per kg of sludge treated is -3 (no digestion), 10 and 6% in options 1, 2 and 3 respectively.	🟩	🟩	🟥	🟨
Pollution prevention Options 1 and 3 remove harmful organic substances from circulation but inorganic compounds and heavy metals are retained in ash/char. BAU and option 2 do not remove metals or microplastics but some pharmaceuticals decompose.	🟥	🟩	🟥	🟩
Material reduction BAU and options 2 and 3 reduce the outgoing material stream by a third. Option 1 halves the material output.	🟨	🟩	🟨	🟨
Climate change mitigation Compared to BAU, sludge management option 2 has a similar carbon footprint per kg of sludge treated. Options 1 and 3 have lower footprints, -24 and -63%, respectively.	🟥	🟨	🟥	🟩
N recovery[4] In BAU and option 2, nitrogen is partly retained in fertiliser products and soil amendments. In options 1 and 3, nitrogen (ammonium sulphate) can be recovered from condensation water in sludge drying and air pollution control, but to a lesser extent.	🟩	🟥	🟩	🟨
P recovery[4] Phosphorus output streams of BAU and options 2 and 3 are roughly on the same level. The smallest amount of total phosphorus is contained in the output of option 1.	🟩	🟥	🟩	🟩
C recovery Option 2 supports carbon recycling while part of C is lost to the atmosphere in option 3 and BAU, and all C in option 1.	🟨	🟥	🟩	🟨

Conclusions and recommendations

None of the sewage sludge management options outweighed the others in all impact categories.

Preferred sludge management options depend crucially on how the different treatment objectives are weighted. Based on an expert workshop organised during the project, **reducing the risks associated with harmful substances and enabling nutrient recycling** are considered the most important sludge management objectives by the stakeholders[5] of the sludge management chain in Finland. Notably, the war in Ukraine and economic sanctions against Russia have further emphasised the need for **security of the supply of nutrients** for agriculture and industry. In addition, mitigation of climate change calls for **minimising the carbon footprint** of sludge treatment.

The most important trade-offs are that

- Reducing the risks associated with harmful substances by sludge incineration means deteriorating opportunities for nutrient recycling. Nitrogen is lost to a great extent but phosphorus recovery from ash is possible by the deployment of (currently still costly) technologies. Some countries have also decided to store ash in anticipation of better nutrient cost competitiveness in the future.
- Production of recycled fertilisers from sewage sludge-based digestate by thermal drying and granulation is associated with high energy consumption, which limits the possibilities for transport biofuel production and is reflected in the higher carbon footprint compared to the other studied sludge management options. However, recycled P fertilisers may still well be a climate-friendly alternative to mineral P fertilisers[6].

Realising the partly contradictory objectives of pollution prevention, maximised nutrient recycling and minimised GHG emissions simultaneously calls for:

- Considering phosphorus recovery in the design and renovation of large WWTPs even if recovery processes would not be realised yet. This would enable P recovery from wastewater before it is bound to sludge with pollutants.
- A dedicated treatment process for reject waters from digestate dewatering for medium-sized and large biogas plants. Especially nitrogen treatment and its recovery are beneficial due to reducing capacity demand of WWTPs and reducing the wastewater fees of centralised biogas plants.
- More research on the pyrolysis management option, which has a low carbon footprint, as well as on the properties of sewage sludge-based biochar.

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[4] All nutrients in the outputs are not readily available for plants. For estimates on bioavailable N and P, see full report (*https://tinyurl.com/sewagesludge*).

[5] Sludge producers, processors and end-users in farming, food industry and landscaping, authorities, researchers.

[6] For more information, see *https://www.researchgate.net/publication/337015530_Environmental_and_health_co-benefits_for_advanced_phosphorus_recovery_Nature_Sustainability*.

The Sustainable Biogas project worked together with the biogas sector and various stakeholders to reduce nutrient discharges from the whole production chain of the biogas production: from the handling of raw materials to the production and to the safe utilisation of nutrient-rich digestates.

According to the results of the project, sustainable nutrient management in biogas production requires careful consideration when planning, permitting and operating the biogas facilities so that the regional nutrient balance is considered, storages for the feedstocks and digestates are adequate and appropriate, and digestate application is based on the plant needs.

Improving the quality of recycled nutrients and promotion of their use are needed. In addition, the reconciliation of the partly contradictory objectives for sewage sludge management - pollution prevention, nutrient recycling and climate change mitigation - should be continued.

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