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# Study on the possibilities of the utilisation of sewage sludge in the Danube Region

*November 2024*

This document was supported as part of DRP-PAC-PA4, an Interreg Danube Region Programme project co-funded by the European Union and partner states and institutions.

# Study on the possibilities of the utilisation of sewage sludge in the Danube Region

An update of “Preparatory study on sewage sludge management in the Danube Region” - 2020

**Assigned by the**

Ministry of Foreign Affairs and Trade of Hungary

**Co-ordinated by the**

EU Strategy for the Danube Region Priority Area 4 – Water quality

**Prepared by**

TRENECON

TRENECON Consulting and Planning Ltd.

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Views expressed in this study are solely those of TRENECON Ltd. and do not reflect the official opinion of either the EU Strategy nor the Danube Region or the Hungarian Ministry of Foreign Affairs and Trade.

During the preparation of this study, Artificial Intelligence was used.

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# Abbreviations

| | |
|---|---|
| BAT | Best Available Techniques |
| BREF | Best Available Techniques Reference Documents |
| C/N | Carbon, Nitrogen |
| CAPEX | Capital Expenditure |
| CFB | Circulating Fluidised Bed |
| CMCs | Component Material Categories |
| COD | Chemical Oxygen Demand |
| COP21 | Paris Agreement |
| DRBMP | Danube Region Basin Management Plan |
| EACI | European Association for Creativity & Innovation |
| EBRD | European Bank for Reconstruction and Development |
| EC | European Commission |
| EEC | European Economic Community |
| EIB | European Investment Bank |
| ENERCOM | ENERgy from COMpost |
| EQS | Environmental Quality Standards |
| EU | European Union |
| EUSDR | European Union Strategy for the Danube Region |
| EUSDR PA4 | European Union Strategy for the Danube Region, Priority Area 4 |
| FB | Fluidised Bed |
| GHG | Greenhouse Gas |
| GMBH | Gesellschaft mit beschränkter Haftung |
| HMFAT | Hungarian Ministry of Foreign Affairs and Trade |
| IAWD | Internationale Arbeitsgemeinschaft der Wasserwerke im Donaueinzugsgebiet |
| IPPC | Integrated Pollution Prevention and Control |
| JCR | Joint Research Centre |
| MSW | Municipal Solid Waste |
| MW | Molecular Weight |

| | |
|---|---|
| N, P | Nitrogen, Phosphorus |
| NOx | Nitrogen Oxides |
| OECD | Organisation for Economic Co-operation and Development |
| OPEX | Operating Expense |
| p.e | Population Equivalent |
| PAs | Priority Areas |
| RES | Renewable Energy Sources |
| REVAQ | Reduction Of Contaminants In Waste Water |
| SMEs | Small and Mid-Size Enterprises |
| SNB | Slibverwerking Noord-Brabant |
| Syngas | Synthetic Gas |
| tDM | Tonnes of dry Mass |
| UWWTD | Urban Waste Water Treatment Directive |
| WFD | Water Framework Directive |
| WWTP | Wastewater Treatment Plant |

# Executive summary

This study examines the management of sewage sludge in the Danube Region, focusing on its treatment, recovery, and utilization. It was conducted under the framework of the EU Strategy for the Danube Region's Priority Area 4 (EUSDR P4), which involved with water quality and sustainability. This report is the continuation of the work of the EUSDR P4 on sewage sludge that started half a decade ago. An important milestone of this work was the "Preparatory study on sewage sludge management in the Danube Region[1]" in 2020-2021 and the "Workshop on Sewage Sludge Management in the Danube Region for a Greener EU" in 2021. The work now aims to update the data on sludge production and recovery, to discuss important recent policy developments and to give an insight into the issue through a survey targeting professionals on the overall issue of sewage sludge management.

The report evaluates the dual role of sewage sludge as both a valuable resource and a potential environmental risk. The scope of the study includes urban sewage sludge only while excluding agricultural and industrial sludge due to their special characteristics. With increasing sludge production driven by population growth, urbanization, and stricter environmental regulations, the study explores opportunities for resource recovery, including its use in agriculture and energy production. It also reviews legislative frameworks, country-specific practices, and emerging challenges, providing a foundation for strategic planning and regional cooperation.

The study incorporates an analysis of current EU and national policies, a survey among regional stakeholders, and a review of best practices. It identifies key challenges such as the variability of sludge treatment methods, public concerns over safety, and the growing presence of emerging contaminants. By aligning its findings with EU goals such as the Green Deal, Circular Economy Action Plan, and Zero Pollution Action Plan, the study offers insights into how sewage sludge management can support sustainable development while mitigating environmental risks.

### Main Findings

Sewage sludge in the Danube Region represents both an opportunity and a challenge. On one hand, its high organic content and nutrient value make it a potential resource for agriculture and energy recovery. On the other hand, public skepticism about the safety of its use, driven by concerns over heavy metals, pathogens, and pollutants like microplastics, remains a significant barrier. The study highlights the wide variability in sludge treatment and recovery practices across the region, shaped by differences in economic capacity, infrastructure, and regulatory frameworks.

In upstream countries such as Germany and Austria, advanced technologies like incineration and phosphorus recovery are more commonly employed, supported by strong economic and legislative structures. In contrast, downstream countries face challenges

[1] https://waterquality.danube-region.eu/preparatory-study-on-sewage-sludge-management-in-the-danube-region-2/

related to inadequate wastewater treatment infrastructure, with lower rates of tertiary treatment and higher reliance on agricultural reuse. Emerging contaminants further complicate the safe use of sludge, with insufficient monitoring and inconsistent reporting systems across the region hindering a comprehensive understanding of its quality and environmental impacts.

The alignment of sludge management practices with EU strategies is a critical issue. The study underscores the relevance of the European Green Deal, the Circular Economy Action Plan and Zero Pollution Action Plan that emphasize the sustainable use of resources and the reduction of environmental risks. However, the existing legislative framework, particularly the Sewage Sludge Directive, requires updates to address modern contaminants and harmonize practices across member states.

### Recommendations

The study emphasizes the need for an updated and harmonized regulatory framework to address the challenges of sewage sludge management in the Danube Region. The ongoing revision of the Sewage Sludge Directive is highly supported to include emerging pollutants such as microplastics and pharmaceuticals and to establish consistent standards across all member states. Introducing EU-wide criteria for the management of treated sludge would support its integration into circular economy practices.

Technological innovation and adoption are also highlighted as key priorities. Investments in advanced treatment technologies such as mono-incineration and phosphorus recovery can enhance nutrient extraction and energy production while minimizing environmental risks. At the same time, the study recognizes the need for cost-efficient solutions tailored to the economic and infrastructural constraints of middle and downstream countries. Research into innovative methods and pilot projects in these areas is strongly recommended.

Regional co-operation is identified as a crucial element for progress. Establishing platforms for knowledge exchange and collaboration can help countries share best practices and standardize monitoring protocols. Joint investments in regional treatment facilities and infrastructure, supported by international financial institutions, are also proposed as a way to improve efficiency and sustainability.

Public awareness and engagement are essential for addressing negative perceptions about sludge reuse. Education campaigns should focus on highlighting the benefits of sustainable sludge management while ensuring transparency through certification schemes for sludge-derived products. Building trust among stakeholders, including farmers, industries, and the general public, is a key step toward greater acceptance of these practices.

Finally, the study calls for integrated policy implementation. Aligning sludge management strategies with broader initiatives in water quality, agriculture, and energy can create synergies and maximize resource efficiency. Collaboration among policymakers, industries, and environmental organizations will be essential for achieving the ambitious sustainability goals set by the EU and ensuring the effective use of sewage sludge as a valuable resource.

# 1 Introduction

Historic data and projections for Europe show that the volume of sewage sludge has been steadily growing which trend also applies to the countries in the Danube Region. At the same time, it is understood that sewage sludge is not necessarily a waste product to be disposed of, but it can be a valuable agricultural raw material to be used after obligatory examination and treatment for increasing organic content of soils or replenishment of phosphorous and other nutrients or trace elements and can also serve as a secondary source of energy. Nevertheless, we have to be aware that there is a strong objection to agricultural use of sewage sludge because of its assumed or inadequately tested and approved hazardous/non-hazardous content, namely heavy metals, pathogens versus high nutrients. There is hardly any resource more readily available and suitable than sewage sludge having high organic matter and nutrient content in an era when arable land has been diminishing, the nutrient content of soils is overly exploited and phosphorous is on the list of critical raw materials.

Recognizing the significance of the issue the EU Strategy for the Danube Region, Priority Area 4 (EUSDR PA4 – to restore and maintain the quality of waters) directed and supported by the Hungarian Ministry of Foreign Affairs and Trade (HMFAT) initiated the elaboration of this study to on sewage sludge treatment and recovery in the Danube Region. The study was carried out by TRENECON Consulting and Planning Ltd. under contract signed with the Hungarian Ministry of Foreign Affairs and Trade.

The scope of this sectoral study elaborated in relation to the actions – primarily to actions 2 and 3 - under Priority Area 4 covers exclusively sewage sludge of agriculture and urban origin. Sludge from industrial production is beyond the scope of the study due to the potential toxic substance content. The ultimate goal of the study is to gather information and provide a background for strategic thinking on the management of sewage sludge.

Sewage sludge management is regulated by a number of EU directives including the Water Framework Directive (2000/60 EC), Urban Waste Water Directive (91/271 EEC), Integrated Pollution Prevention and Control (IPPC) Directive (91/61 EC), Landfill of Waste Directive (99/31 EC) and the Council Directive on sewage sludge used in agriculture (86/278 EEC). The latest EU initiatives include the European Green Deal with the Zero Net Emissions Target as well as the new Circular Economy Action Plan for a cleaner and more competitive Europe (COM(2020)98 final). The EU legislation, compliance at national level were discussed in the study.  In addition, the 2017 list of Critical Raw Materials (COM(2017) 490 final) has been consulted. Scrutiny of relevant strategic and legislation coherence is a key area of the assessment. For most of the countries of the EUSDR, EC documents, strategies and legislation are binding; countries are at different levels in fulfilling the requirements set in the community legislation. Whereas some countries have specific sludge management and recovery strategies, others manage sludge in line with the criteria set out in their water and sewage management strategies. There are differences in the administrative backgrounds, the focus and the applied techniques however common points in management exist and targets common in nature are derived from the EC legislation and strategies.

Regardless of the embeddedness of countries actions into EU legislation, sludge can be considered an important resource and, at the same time, a risk for the environment in all EUSDR countries concerning soil and water quality as well as human and livestock health.

Although the different geographical, social and economic characteristics of the countries mean that the sludge-related challenges faced and the answers proposed are also different, several problems can be identified that have strong relevance in all countries. In the case of such challenges a platform for co-operation, exchange of best practices between countries could lead to better answers everywhere.

The first part of the study briefs on specific sludge related legislation, strategies and activities within the countries; this analysis mostly relies on information published in professional papers, or available on the internet. Also, the representatives of important stakeholders within the Danube Region were interviewed including the International Commission for the Protection of the Danube River. An important elements of the study is a survey carried out among professionals focusing on the problems related to the sludge management problems in the entire region. The second part of the study focuses on the newly emerging challenges, including new policy developments. Lastly, the study tries to give clear indication of the possible forms and themes of common thinking on sludge management within the EUSDR.

# 2 Community strategy and legislation

## 2.1 Strategic documents related to sludge management

In the recent period, the European Union adopted a number of strategies that are the basic foundations of the future of economic activities. Here the strategies with relevance to sludge management are discussed starting with the most comprehensive ones and also, the more specific sectoral strategies are presented briefly.

**Green Deal**[2]

Its main goal is to make the European Union climate-neutral by 2050, to be achieved in various target areas regulated by specific legislation:

- Clean energy
  - decarbonising the energy sector and the energy-intensive industries, turning the industry to green technologies, modernising buildings, ecodesign of products and planning of energy efficiency
    - increasing the share of renewable energy sources
    - reducing GHG emissions
    - cutting back on final energy consumption
- Rolling out cleaner, cheaper and healthier forms of transport
- Circular economy
  - increasing the rate of reuse and recycling
  - decreasing the quantity of dumped municipal solid waste (MSW)
- Resource efficiency, respect of the resource constraint
- Zero pollution for air, water and soil
- Clean water: achieving a good water status
- Clean air
- Preserving/enhancing biodiversity in urban environment
- Adapting to climate change
- Farm to Fork

[2] The European Green Deal; Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions; COM(2019) 640 final; https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en

According to the above targets, the policy areas of the Green Deal are as follows (see their brief discussion below under separate headings):

- Clean Energy
- Sustainable Industry
- Building and Renovation
- Farm to Fork
- Eliminating pollution
- Sustainable mobility
- Biodiversity

An important objective is to implement these goals in a financially sustainable way.

Sludge reuse is suitable for contributing to the achievement of the goals related to good water status, the circular economy, resource efficiency, sustainable food production and reduction of GHG emissions. The opportunities for reuse are narrowing, however, due to the requirements, more stringent waste management requirements and costs, which could lead to a strengthening of waste disposal.

### Circular economy[3]

The Circular Economy Action Plan sets out measures with the aim of “fully closing” the circular economic cycle and regulating product life cycle in each of its phases – from production and consumption up to waste management and the secondary raw material market.

Waste prevention, ecodesign, reuse promotion and other similar measures may signify cost savings for business undertakings operating in the European Union in an amount of net 600 billion EUR, i.e. amounting to 8% of their annual turnover, while they can decrease the total annual GHG-emissions by 2 to 4%.

Sewage sludge is suitable for recovery from several aspects and it may acquire a role as a measure that can be implemented in the framework of circular economy under the support schemes for the period 2021-2027, while contributing to diverting sewage sludge dumped in excess from landfills.

### “Farm to Fork” Strategy[4]

The aim of the strategy is to accelerate the transition to a sustainable food system in a way so that it should

- entail a neutral or positive environmental impact,

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[3] A new Circular Economy Action Plan For a cleaner and more competitive Europe; Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions; COM/2020/98 final https://ec.europa.eu/environment/circular-economy/

[4] A Farm to Fork Strategy for a fair, healthy and environmentally-friendly food system; Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions; COM/2020/381 final; https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52020DC0381

- contribute to the mitigation of the impacts of climate change and adaptation to them,
- promote the reversal of the loss of biodiversity,
- ensure food, nutrition and public health security and guarantee access for all to sufficient, secure, nutritious food from sustainable sources,
- preserve affordability of food, by simultaneously ensuring a fairer economic return, by promoting fair trade and the competitiveness of the supply sector of the European Union.

Waste water and the compost produced by pre-treatment of the sewage sludge are important fertilising products even according to the most recent strategies of the Commission, which can also be used in sustainable food production, after having undergone appropriate pre-treatment and after extraction of the pollutants, without putting the fundamental goals of sustainable food production to risk. These issues are recognised in the Regulation (EU) 2019/1009 of the European Parliament and of the Council of 5 June 2019 laying down rules on the making available on the market of EU fertilising products and amending Regulations (EC) No 1069/2009 and (EC) No 1107/2009 and repealing Regulation (EC) No 2003/2003 under paragraph 58) where it's stated:

> *"Promising technical progress is being made in the field of recycling of waste, such as phosphorus recycling from sewage sludge, and fertilising product production from animal by-products, such as biochar. It should be possible for products containing or consisting of such materials to access the internal market without unnecessary delay when the manufacturing processes have been scientifically analysed and process requirements have been established at Union level."*

It is also laid down in the above regulation concerning the use of sludge and the Farm to Fork Strategy that (Part II - Requirements Related to Component Material Categories)

"CMC 3: COMPOST:

*1. An EU fertilising product may contain compost obtained through aerobic composting of exclusively one or more of the following input materials:*

*…*

- *(c) living or dead organisms or parts thereof, which are unprocessed or processed only by manual, mechanical or gravitational means, by dissolution in water, by flotation, by extraction with water, by steam distillation or by heating solely to remove water, or which are extracted from air by any means, **except**:*

*…*

- *sewage sludge, industrial sludge, or dredging sludge…*"

### Zero pollution action plan[5]

The strategy concludes that pollution to air, water and soil are important drivers of loss of biodiversity and largely contributes to the extinction of species.

Society must reckon with a decreasing number of services the ecosystems can provide, including the increase of costs such as health care, working days lost, declining productivity, and decreasing yields (e.g. agriculture, fishing and tourism).

The costs of water treatment, soil decontamination, sea decontamination and those of restoring the ecosystem services (e.g. pollination) are increasing. Pollution avoidance will gain more importance and sewage sludge disposal to the environment will become more and more expensive without treatment than pre-treated. There could be a return on pre-treatment costs at the level of society as well, if there is no pollutant content of the disposed sludge of if it is decreased considerably.

Pollution is closely interrelated with other environmental and social risks affecting the business undertakings and the citizens. The current restoration efforts provide an opportunity for increasing social resilience and social sustainability by reducing the level of pollution affecting the different groups of citizens.

Through the implementation of the strategy safe, secure and sustainably conceived, low-emission technologies will have a greater role, and priority will be given to sustainable innovation and an environmentally cleaner economic upswing, to “green growth”.

### Chemicals strategy for sustainability towards a toxic-free environment[6]

The strategy is mainly about chemicals, but it deems that in a clean circular economy it is essential to boost the production and uptake of secondary raw materials. Another interrelated key goal is the achievement of non-toxic material cycles.

It emphasizes as an essential requirement that both primary and secondary substances and products should always be safe. These requirements must be taken into account when re-using any waste as product. A support scheme is planned to be established in order to decontaminate waste streams, increase safe recycling and reduce the export of waste. One of the priority goals is recycling of sewage sludge and turning it to a product, but attention must be paid to its hazardous substance content, which can be reduced only by pre-treatment, but this is necessary for its safe use in terms of chemistry.

[5] EU Action Plan “Towards a Zero Pollution Ambition for air, water and soil – building a Healthier Planet for Healthier People; https://ec.europa.eu/environment/strategy/zero-pollution-action-plan_en#ecl-inpage-208

[6] Chemicals Strategy for Sustainability Towards a Toxic-Free Environment; Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions; 14.10.2020 COM(2020) 667 final; https://ec.europa.eu/environment/pdf/chemicals/2020/10/Strategy.pdf

### EU Biodiversity Strategy for 2030[7]

The enhancement of the status and diversity of ecosystems, besides its overall relevance to the quality of life and bioethics, can improve the resilience to climate change, the environmental risks and to socio-economic shocks. The new approach is relevant in many sectors and is expected to create new jobs in organic farming, rural tourism and in the recreational sector, among others.

The strategy primarily targets protected areas but the restoration of habitats in general is also in the forefront of the policy (see sub-section: 2.2.2. Bringing nature back to agricultural land; 2.2.3. Addressing land take and restoring soil ecosystems; 2.2.4. Increasing the quantity of forests and improving their health and resilience; 2.2.6-7. Restoring the good environmental status of marine and freshwater ecosystems; 2.2.9. Reducing pollution under Section 2.2: An EU Nature Restoration Plan: restoring ecosystems across land and sea). The strategy gives priority to restraining land use change and restoring the soil ecosystems. It concludes that the degradation of soil has led to major environmental and economic consequences in the European Union. Poor land management, such as deforestation, overgrazing, unsustainable farming and forestry practices, construction activities and land sealing are among the main causes of this situation.

Sewage sludge and other substances derived from its treatment could play a role in this respect as well, both in forestry and farming practices as a substance providing nutrient refurbishment. Specifically, the materials derived from sludge may be important in regards to the specific goals of the strategy in regards to the restoration of habitats (EU Nature Restoration Plan to be developed under the strategy) aiming at, for example reducing the use of fertilisers, planting trees and the recultivation of degraded land and the proper management of sludge contributes to decreasing pollution and the restoration of the water ecosystems.

### Bioeconomy Strategy[8]

The purpose of the review of the bioeconomy strategy in 2018 was to accelerate the deployment of a sustainable European bioeconomy, in order to implement the 2030 Sustainable Development Goals. The strategy is based on three main priorities:

- strengthening and extending bioeconomies
- deployment of local bioeconomies across Europe
- exploring and understanding local economic constraints to implement a bioeconomy

[7] EU Biodiversity Strategy for 2030 Bringing nature back into our lives; Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions; COM/2020/380 final; https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1590574123338&uri=CELEX:52020DC0380

[8] A sustainable Bioeconomy for Europe: Strengthening the connection between economy, society and the environment; Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions; COM/2018/673 final; https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52018DC0673

### Thematic Strategy for Soil Protection COM(2006)231[9]

According to the situation assessment carried out in the framework of the strategy soil degradation is a serious problem in Europe. It is driven or exacerbated by human activity such as inadequate agricultural and forestry practices, industrial activities, tourism, urban and industrial sprawl and construction works.

These activities have a negative impact, preventing the soil from performing its broad range of functions and services to humans and ecosystems. This results in loss of soil fertility, carbon and biodiversity, lower water-retention capacity, disruption of gas and nutrient cycles and reduced degradation of contaminants. Appropriately treated sewage sludge can be a substance with some pollutant content, the extent of which should be such, however, that does not lead to soil degradation and it can even help in soil rehabilitation.

According to the position of the Commission, soil degradation has an impact on the status of other environmental elements as well, because they have a mutual impact on each other through complex interactions. The degradation of soils might entail a deterioration in water and air quality, and might undermine the achievement of EU objectives in terms of biodiversity protection and action against climate change.

The Commission has formulated the possible cross-border impacts of soil loss as a further reason. Even though soils cannot be considered a mobile medium, in certain cases a soil degradation process might have cross-border consequences.

### The EU's new Soil Protection Thematic Strategy[10]

The Soil Protection Thematic Strategy is planned to constitute part of the EU Biodiversity Strategy for 2030, with the aim of updating the current strategy for checking and halting soil degradation and preserving the soil as a resource.

The strategy serves the achievement of the following objectives:

- protecting the fertility of soil;
- counteracting erosion and restraining build-up;
- increasing the organic matter content of soils;
- identifying and inventorying contaminated areas;
- restoring the soils of a degraded status;
- identifying the criteria for classifying soils as being in a good ecological status.

A wide-scale consultation and coordination is in course about the strategy, it is expected to be adopted in 2021. Sewage sludge recovery is aligned with several of the soil protection

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[9] Thematic Strategy for Soil Protection; Communication from the Commission to the Council, the European Parliament, the European Economic and Social Committee and the Committee of the Regions - [SEC(2006)620] [SEC(2006)1165]/ /* COM/2006/0231 final */; https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52006DC0231

[10] Proposal for a Directive of the European Parliament and of the Council establishing a framework for the protection of soil and amending Directive 2004/35/EC/* COM/2006/0232 final - COD 2006/0086 */; https://ec.europa.eu/environment/soil/three_en.htm
New Soil Strategy - healthy soil for a healthy life;
https://ec.europa.eu/environment/soil/index_en.htm
https://ec.europa.eu/environment/water/index_en.htm

objectives, for example, it can be used for preservation of fertility, increasing the organic matter content of soils and restoring degraded soils.

### Opinion of the European Economic and Social Committee on the sustainable use of phosphorus[11]

Opinion 2014/C 177/14 of the European Economic and Social Committee has a primary focus on the issue of sustainable use of phosphorus, thus it focuses on its use in agriculture.

The resolution is fundamental for promoting the move towards a "precision agriculture", with paying a greater attention to local needs and availabilities. It would provide a solution for this problem not primarily by legislation, rather by elaborating an appropriate incentive system. Efforts must be made for cutting primary phosphorus consumption back, for a greater rate of use of organic matter, and for a secure recycling of substances rich in phosphorous but currently classified in the status of waste, such as sewage sludge, so that a marketable product can be made from waste.

### EU strategy to reduce methane emissions[12]

The most important aspect formulated in the strategy that can be linked to sewage sludge is biogas production. Non-recyclable human waste can be recovered in digestive basins using anaerobic technology for the purpose of biogas production, while in biorefineries for producing biological substances and biochemical intermediate substances.

Such raw materials, while used for biogas production, can effectively contribute to reducing methane emissions deriving from anaerobic biodegradation taking place in nature. Biogas derived from such processes is a highly sustainable and useful renewable energy source with lots of fields of application. The biodegradation residue can be used, after having undergone further processing, as soil improver and thereby the need for fossil-based fertilisers can be decreased.

Biogas production may signify a further revenue source for farmers and provides opportunity for development and investments in rural areas, which in turn requires cooperation with the farmers and the local communities.

Untreated sewage sludge can cause uncontrolled emissions of methane in water-related media. Although the implementation of the UWWTD helped prevent significant emissions already, the European Commission have announced that to support the evaluations of the Sewage Sludge Directive further studies are to be made and measures are to be considered to limit GHG emissions in relation to the Sewage Sludge and Urban Waste Water Treatment Directives.

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[11] Opinion of the European Economic and Social Committee on the 'Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions — Consultative communication on the sustainable use of phosphorus' COM(2013) 517 final https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A52013AE6363

[12] EU strategy to reduce methane emissions; Communication from the Commission to the Council, the European Parliament, the European Economic and Social Committee and the Committee of the Regions; Brussels, 14.10.2020; COM(2020) 663 final; https://ec.europa.eu/energy/sites/ener/files/eu_methane_strategy.pdf

### General Union Environmental Action Programme to 2030 (8th Environmental Action Programme)[13]

European Commission published a proposal for an 8th Environment Action Programme (EAP) on 14 October 2020." The concept of the action programme fundamentally relies on the UN sustainable development goals and the goals enshrined in the Paris Agreement (COP21).

The issue of recovery of sewage sludge can be matched to the priority objectives of the programme:

- pursuing a zero-pollution ambition for a toxic free-environment, including for air, water and soil, and protecting the health and well-being of citizens from environment-related risks and impacts;
- promoting environmental sustainability and reducing key environmental and climate pressures related to production and consumption, in particular in the areas of energy, industrial development, buildings and infrastructure, mobility and the food system.

The adoption of the 8th Environment Action Plan is foreseen to take place in 2020, but the programme will set the main directions and course of environmental protection action from 2021 onwards.

### European Union Strategy for the Danube Region[14]

The EUSDR was adopted by the European Commission in December 2010 and codified by the European Council in 2011, under Hungarian EU Presidency. The EU Strategy for the Danube Region was detailed in its Action Plan which was renewed in 2020; the new plan has in total 12 Priority Areas (PAs) and defined 85 actions. Among these action sludge management may have relevance to the following priority areas:

PA2: Sustainable Energy: the PA is involved with the further exploration of the sustainable use of clean biomass, solar energy, geothermal, hydropower and wind power to increase the energy independency and to promote and support multipurpose cross border RES utilisation projects.

PA4: Water quality: PA4 aims at maintaining and restoring the quality of waters in the Danube Region, especially related to organic substances, nutrients, hazardous and emerging substances inter alia by enhancing waste water treatment and by promoting best management practices.

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[13] General Union Environmental Action Programme to 2030; Proposal for a Decision of the European Parliament and of the Council; Brussels, 14.10.2020COM(2020) 652; final 2020/0300 (COD) https://ec.europa.eu/environment/strategy/environment-action-programme-2030_hu

[14] European Union Strategy for Danube Region; Communication from the Commission to the Council, the European Parliament, the European Economic and Social Committee and the Committee of the Regions; Brussels, 8.12.2010 COM(2010) 715 final

Action Plan Replacing Staff Working Document SEC(2010) 1489 final accompanying the Communication from the Commission to the Council, the European Parliament, the European Economic and Social Committee and the Committee of the Regions; European Union Strategy for Danube Region - Brussels, 6.4.2020 SWD(2020) 59 final; https://ec.europa.eu/regional_policy/en/policy/cooperation/macro-regional-strategies/danube/

PA5: Environmental risk: the priority area focuses on all aspects of risk management related to floods and accidental pollution, including traditional means and also cutting edge solutions, such as wetland and floodplain restoration, spatial planning and aspects of climate change.

PA6: Biodiversity and landscapes, quality of air and soils: this unique region and its natural values are under growing pressure due to urban sprawl and development of agriculture, industry, transport and tourism, often resulting in: loss of biodiversity and variety of ecosystems.

## 2.2 Community legislation

### Legislation directly related to sludge management

**Council Directive 86/278/EEC of 12 June 1986 on the protection of the environment, and in particular of the soil, when sewage sludge is used in agriculture**

The directive defines the most important notions and fundamentals and establishes prohibitions (in particular: for crops, the time of spreading of the sludge, limit values for heavy metal content), which have been determining the constraints on the use of sewage sludge for more than three decades.

When sludge is used, the sludge must be treated and used in such a way that account is taken of the nutrient needs of the plants and that the quality of the soil and of the surface and ground water is not impaired. Where sludge is used on soils of which the pH is below 6, the increased mobility and availability to the crop of heavy metals must be taken into account and the Member States shall, if necessary, reduce the limit values they have laid down in accordance with Annex I A.

The directive prescribed the requirement of regularly analysing the sludge and the soil on which sludge is spread and includes a reporting obligation for the Member States. The directive lays down the limit values for heavy metals, but the national standards may apply a different, more stringent system.

**Council Directive 91/271/EEC of 21 May 1991 concerning urban waste-water treatment**

The directive primarily lays down the rules for disposal, treatment and discharge to receiving waters of urban waste water and sets deadlines for the obligations.

It formulates as a fundamental requirement with respect to sewage sludge that the disposal of sludge to surface waters should be phased out. Sludge arising from waste water treatment must be re-used whenever appropriate. Disposal routes shall minimize the adverse effects on the environment.

**Regulation (EU) 2019/1009 of the European Parliament and of the Council of 5 June 2019 laying down rules on the making available on the market of EU fertilising products and amending Regulations (EC) No 1069/2009 and (EC) No 1107/2009 and repealing Regulation (EC) No 2003/2003**

According to the Regulation promising technical progress is being made in the field of recycling of waste, such as phosphorus recycling from sewage sludge, and fertilising product production from animal by-products, such as biochar. It should be possible for products containing or consisting of such materials to access the internal market without unnecessary delay when the manufacturing processes have been scientifically analysed and process requirements have been established at Union level. With respect to an EU fertilising product, the directive identifies sewage sludge, industrial sludge and dredging sludge as input materials; and the EU fertilising product that may contain compost obtained through aerobic composting of one or more of the input materials.

The Regulation sets out that an EU fertilising product shall consist solely of component materials complying with the requirements for one or more of the Component Material Categories (CMCs) listed in Annex II to the Regulation. In this Annex sewage sludge (and other sludge derived by a similar methods) is listed as an exception, thus it shall not be used either as compost or as digested fertiliser component unless solid scientific evidence exist on it harmlessness to agricultural production and the environment.

### Other related legislation

#### Water Framework Directive (WFD) and related legislation

Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy sets forth that further integration of protection and sustainable management of water and its streamlining into other Community policy areas such as energy, transport, agriculture, fisheries, regional policy and tourism is necessary. In order to achieve and preserve good water status, the Directive sets detailed goals concerning surface waters, groundwater and protected areas – one of the tools for it being water pollution prevention and reduction of pressure reaching water bodies, which also consist of, among many other tools, a responsible organisation of water services. Responsible organisation of water services also includes waste-water treatment and, as part of it, the reuse of treated waste water and sewage sludge in a way that does not entail direct or indirect risk of water pollution and allows achieving good water status.

#### Directive of Environmental Quality Standards in the field of water policy (Directive 2008/105/EC)

This Directive, rooted in the WFD, lays down environmental quality standards (EQS) for priority substances and certain other pollutants, with the aim of achieving good surface water chemical status and in accordance with the provisions and objectives of Article 4 of Directive 2000/60/EC.

Regulation is implemented at two levels: for a more effective regulation of surface water protection, the EQSs are set up at Community level for pollutants classified as priority substances, while it is left to the Member States to lay down rules relevant to river basin specific pollutants at national level, subject to the application of relevant Community rules. The Directive sets annual averages and maximum allowable concentration for several substances, and some of these substances can also be found in sewage sludge, therefore the Directive also regulates sludge use and usability.

#### Groundwater Directive (2006/118/EC)

Directive 2006/118/EC, also rooted in the WFD, on the protection of groundwater against pollution and deterioration establishes specific measures in order to prevent and control groundwater pollution, preserve good chemical status of water bodies and prevent its deterioration. It sets out a number of requirements in order to reduce detrimental concentrations of harmful pollutants in groundwater.

It defines the scope of measures intended for preventing or limiting inputs of pollutants into groundwater in detail, based on which disposal and use of sewage sludge is also limited.

### Regulation (EU) 2020/741 of the European Parliament and of the Council of 25 May 2020 on minimum requirements for water reuse

The purpose of this Regulation is to facilitate the uptake of water reuse whenever it is appropriate and cost-efficient. It creates an enabling framework for those Member States who wish or need to practise water reuse. In reusing waste water from urban waste water treatment plants is an option, but in agricultural use special attention must be paid to food hygiene, for which uniform requirements are needed.

Water reuse – on the basis of an approved water reuse risk management plan – could contribute to the recovery of the nutrients contained in treated urban waste water, and the use of reclaimed water for irrigation purposes in agriculture or forestry could be a way of restoring nutrients, such as nitrogen, phosphorus and potassium, to natural biogeochemical cycles.

### Council Directive 1999/31/EC of 26 April 1999 on the landfill of waste

Waste water and sewage sludge do not fall within the scope of Council Directive 1999/31/EC on the landfill of waste. The Directive sets forth that without prejudice to existing Community legislation, the spreading of sludge including sewage sludge, and sludge resulting from dredging operations, and similar matter on the soil for the purposes of fertilisation or improvement, are excluded from the scope of the Directive.

The principal objective of the Directive is that the Member States should take the necessary measures so that the volume of municipal waste dumped in landfill is decreased by 2035 to 10% by weight of the total municipal waste generated. In European practice sewage sludge serves in many cases for recultivation of landfills, but a major goal of the Directive is that priority should be given to diverting as much waste as possible from landfills, with a primary preference for reuse and recycling.

### 2017 list of Critical Raw Materials for the EU (COM(2017) 490 final)

The primary purpose of the list is to identify the raw materials with a high supply-risk and a high economic importance to which reliable and unhindered access is a concern for European industry and value chains, as well as to identify investment needs which can help alleviate Europe's reliance on imports of raw materials.

Another purpose of the list is to help incentivise the European production of critical raw materials through enhancing recycling activities and when necessary to facilitate the launching of new mining activities. Phosphorus has also been included in the list, which is contained in sewage sludge in great quantity.

### Nitrates Directive (91/676/EEC)

Sewage Sludge is defined by the Directive concerning the protection of waters against pollution caused by nitrates from agricultural sources (91/676/EEC) as a substance containing a nitrogen compound or nitrogen compounds utilized on land to enhance growth of vegetation. Given that excessive use of fertilizers constitutes an environmental risk, which might lead to water pollution, therefore, the Directive lays down detailed rules for all aspects and quantities for storing and spreading fertilisers and designates them with the collective term of good agricultural practice.

Observance and respect of good agricultural practices can provide all waters with a general level of protection against pollution in the future.

### Directive 2010/75/EU on industrial emissions (integrated pollution prevention and control)

The directive includes a general prohibition on disposal of wastes and in particular wastes also containing heavy metals into any water body and determines emission limit values for installations for emission of pollutants into water. It sets out the main rules for waste incineration and waste co-incineration, including incineration of liquid waste. The Directive also includes restrictions on emissions into soil or water bodies. Sewage sludge may be used for energy production purposes as regulated by the Directive. Best Available Techniques Reference Documents (BREFs) discussed in Chapter 4 are worked out under this Directive.

### Directive 2004/35/CE on environmental liability with regard to the prevention and remediation of environmental damage

The Directive lays down the “polluter pays” principle, a comprehensive and fundamental liability rule in environment protection, allows in principle for the Member States to consider the spreading of sewage sludge from urban waste water treatment plants and treated to an approved standard, not as a waste management operation.

The Directive sets out a clear framework for protecting land, in particular soils, with special regard to the operations of installations listed in Annex III. These are unequivocal and obligatory requirements which identify the pollutants and the clauses on biodiversity and water protection also serve for protecting the soil.

The other provisions of the Directive must be taken into account, however, during treatment of sewage sludge in any form, because the components of sewage sludge are prone, without treatment, to cause environmental harm both in soils and in surface water and groundwater.

### Environmental Impact Assessment Directive (85/337/EEC)

Pursuant to the Directive, the environmental impact assessment shall identify, describe and assess in an appropriate manner, in the light of each individual case, the direct and indirect effects of a project on the following factors:

a) the population and human health;

b) biodiversity, with special regard to protected species and habitats pursuant to Directives 92/43/EEC and 2009/147/EC;

c) land, soil, water, air and the climate;

d) material assets, the cultural heritage and the landscape;

e) the interaction between the factors referred to in points (a)-(d).

The impacts on the factors listed in points (a)-(e) also include the expectable impacts arising from exposure of the project to the risk of major accidents and/or disasters.

Based on the regulation, the use of sewage sludge is an activity subject to impact assessment if it entails significant environmental impacts. In most of the cases, the impact assessment affects sewage sludge when under the permission procedure for waste water treatment plants it has to be defined and clarified what will happen to the sewage sludge discharged from the installation.

# 3 Major challenges in sludge management

## 3.1 The changing context: new community level strategies

New community level strategies are expected to bring a new era in many fields of environmental protection including sludge management; the main framework of the shift to sustainable development is the European Green Deal. Its action plans and related strategies and the stemming legislation give indications on how certain processes are to be managed. Many of these new policy and legislative papers are under preparation and sludge management systems will need to comply with the new rules; it is expected that the legislative work will be finished in one or two years, however certain directions are already visible.

The main message of the Green Deal is that all socio-economic processes are to be changed in order to achieve energy efficiency, zero pollution and circular economy on the long run. The very ambitious targets are set in the Green Deal in general, and specific details are given in the accompanying action plans and strategies.

The most important element of the strategies is that due to energy scarcity all residual materials in the industrial process shall be used as energy sources if possible (see Green Deal), and secondly, all materials shall be utilised in appropriate economic activities as raw materials; during the recovery processes all pollution has to be avoided. This means that all processes are becoming parts of many times different production cycles using reused material and green energy sources. Sludge has high energy content and contains several materials, notably phosphorus, that are important input materials for the chemical industry and agriculture. Also, the high organic content of sludge can be well utilised in agriculture. These possible uses of sludge are implicitly present in the new strategic documents, however there are considerable limitations to it in relation to pollution control.

Strategies related to agricultural production and biodiversity, also being incorporated into the reform of the Common Agricultural Policy and the 8th Environmental Action Programme, define standards to the production of food and to the maintenance of soils and waters as key resources. This aspect of the initiatives can be well paired with the Zero Pollution Action Plan that aims at the minimising of environmental loads from all sources applying new technologies.

Recognising the changing strategic environment, the review of the water related legislation in general has started with the fitness check of the Water Framework Directive and related directives, notably the Waste Water Directive. Specifically related to sludge, the Commission started a public consultation process on the EU rules set in Directive 86/278 on the use of sewage sludge in farming starting with 20.11.2020. The result of the consultation process (ending April 2021) together with the revision of the Directive will have significant impact on sludge management throughout the entire community and the accession countries.

## 3.2 Recent policy developments

In the recent years there have been lot done in regards the revision of the present legislation and regulations on the management of sludge that reflect the new overall policy aims of the Green Deal and the related strategies. In 2019, the evaluation of the urban waste water directive took place, that was followed by the recast of the directive itself. As an aftermath, in 2021 the revision of the Sewage Sludge Directive started with the evaluation and the preparation of various supporting documents with policy, economic and technology focuses. The outcomes of these processes are summarised below discussing the most important papers leading to the still ongoing finalisation of the sludge related directive and regulations.

**The evaluation of the urban waste water treatment directive[15]**

The evaluation of the Urban Waste Water Treatment Directive (UWWTD) by the European Union (EU) provides a comprehensive review of its effectiveness, efficiency, coherence, relevance, and EU-added value since its adoption in 1991. This assessment, encompassing all EU Member States and the entire implementation period, reveals key insights into the Directive's performance and areas requiring improvement, particularly regarding sewage sludge management.

The UWWTD mandates the establishment of wastewater collection and treatment systems, with specific treatment standards and monitoring requirements. Since its implementation, significant advancements have been achieved in the collection and treatment of urban wastewater. Compliance rates across the EU for the Directive’s requirements are generally high, especially in the EU15 Member States, which demonstrate nearly universal compliance. However, compliance is lower in newer EU Member States (EU13), with notable disparities in the application of more stringent treatment requirements.

**Main findings of the evaluation**

1. Effectiveness

The UWWTD has been highly effective in improving water quality across the EU by reducing pollutants such as nitrogen (N) and phosphorus (P), which contribute to eutrophication. It has also helped lower biochemical oxygen demand (BOD) in water bodies, enhancing aquatic ecosystems and public health. The Directive has driven the modernization of wastewater infrastructure, leading to substantial environmental benefits.

However, gaps remain in addressing pollutants of emerging concern, such as microplastics and pharmaceuticals, which are not explicitly covered by the Directive. Additionally, combined sewer overflows (CSOs) and individual appropriate systems (IAS) have posed challenges, with many Member States struggling to ensure their effective management.

2. Efficiency

Stakeholders agree that the costs of implementing the UWWTD are proportionate to its benefits, particularly in the long term. Nonetheless, the Directive's provisions have sometimes been deemed inflexible, failing to adapt to local conditions or advances in

[15] Evaluation of the Council Directive 91/271/EEC of 21 May 1991, concerning urban waste-water treatment; Commission Staff Working Document; Brussels, 13.12.2019

technology. Investment needs, especially in less developed regions, remain a barrier to full compliance, highlighting the necessity for sustainable financing models.

3. Coherence

The Directive aligns well with broader EU water and environmental policies, such as the Water Framework Directive (WFD) and the Marine Strategy Framework Directive (MSFD). However, better integration with newer policies addressing energy efficiency and climate change is recommended.

4. Relevance

While the UWWTD addresses key environmental challenges, stakeholders indicate that its scope does not fully capture contemporary issues, including climate resilience, stormwater management, and the recovery and reuse of resources like sludge.

5. EU-Added Value

The Directive has proven its value by fostering a uniform approach to urban wastewater management across Member States, ensuring high water quality standards and preventing a fragmented regulatory landscape. The evaluation underscores the necessity of continued EU-level action to maintain and build upon these achievements.

### Sewage Sludge Management in the UWWTD

Sewage sludge plays a critical role in the Directive's implementation and intersects significantly with the Sewage Sludge Directive (SSD). The evaluation highlights both opportunities and challenges in its management.

Sludge contains nutrients like nitrogen and phosphorus, making it suitable for agricultural reuse, which aligns with circular economy goals. However, its use is constrained by concerns over contaminants, such as heavy metals and microplastics, that could pose risks to human health and ecosystems. The current UWWTD framework provides limited guidance on sludge quality and treatment, leaving room for interpretation by Member States and leading to inconsistent practices.

Stakeholders emphasize the need for harmonized standards for sludge quality, particularly regarding contaminants of emerging concern. Advanced treatment technologies, such as anaerobic digestion and thermal hydrolysis, can enhance sludge safety and facilitate resource recovery, yet their adoption varies widely across the EU due to cost and technical barriers.

The reuse of sewage sludge also faces societal and regulatory challenges. Public perceptions about safety and the lack of clear incentives for reuse hinder progress. Furthermore, the SSD's narrow scope limits its effectiveness in addressing the complexities of modern sludge management.

To improve sewage sludge management, the evaluation recommends:

1. Updating the SSD to reflect advancements in treatment technologies and address emerging contaminants.

2. Enhancing the UWWTD's provisions to promote sludge valorization, including phosphorus recovery, as part of a broader circular economy strategy.

3. Supporting research and innovation to develop cost-effective solutions for sludge treatment and reuse.

4. Establishing EU-wide quality standards for sludge to ensure consistency and safety across Member States.

In conclusion, the UWWTD has made significant contributions to environmental and public health protection through improved wastewater treatment. However, challenges such as the management of sewage sludge and the integration of emerging issues into its framework need to be addressed to sustain its relevance and effectiveness in a rapidly evolving context. Future revisions should aim to strengthen the Directive's adaptability and support Member States in achieving its objectives comprehensively.

### Urban Wastewater Treatment Directive[16]

The European Union's Urban Waste Water Treatment Directive (UWWTD), first adopted in 1991 and revised most recently, serves as a comprehensive legislative framework aimed at safeguarding water quality by regulating the collection, treatment, and discharge of urban wastewater. Its overarching objective is to mitigate environmental pollution, protect aquatic ecosystems, and enhance public health by ensuring wastewater is treated effectively before being released into natural water bodies.

### Overview and key provisions of the UWWTD

The UWWTD establishes clear requirements for urban wastewater management across EU Member States. It mandates that urban areas with populations exceeding 1,000 equivalent inhabitants must collect and treat wastewater through centralized systems or individual alternatives where justified. Treatment processes must adhere to minimum standards, including secondary and, where necessary, tertiary or even quaternary treatments to remove pollutants such as nutrients and emerging contaminants.

The directive emphasizes the importance of addressing pollution from combined sewer overflows, urban runoff, and small agglomerations, recognizing their significant contributions to water quality degradation. Additionally, it integrates climate considerations, promoting energy-efficient practices and the use of renewable energy within wastewater treatment facilities. Transparency, data sharing, and public engagement are strengthened through requirements for accessible information on treatment costs, performance, and environmental impacts.

### Sewage Sludge Management in the UWWTD

The revised UWWTD aligns sludge management with other EU policies, including the Sewage Sludge Directive and the broader waste hierarchy principles. By doing so, it seeks to maximize the environmental and economic benefits of sludge reuse while minimizing health risks. However, the directive acknowledges the need for continuous scientific research and technological development to address emerging challenges, such as the presence of pharmaceuticals and antimicrobial resistance in sludge.

Sewage sludge, in the context of the directive, presents both opportunities and challenges in the context of environmental sustainability and public health. The revised UWWTD underscores the critical role of effective sludge management in advancing a circular economy and meeting EU sustainability goals.

[16] Proposal for a Directive of the European Parliament and of the Council concerning urban wastewater treatment (recast); Brussels, 26.10.2022 COM(2022) 541 final

Sewage sludge contains valuable nutrients, particularly phosphorus and nitrogen, which can be reclaimed for agricultural use. To this end, the directive introduces a minimum combined reuse and recycling rate for phosphorus recovery, reflecting its importance as a critical raw material. Member States are encouraged to adopt measures that facilitate the safe reuse of sludge, such as advanced treatment technologies that improve sludge quality while minimizing environmental risks.

Despite its benefits, sewage sludge can contain harmful contaminants, including heavy metals, microplastics, and persistent organic pollutants. The directive mandates systematic monitoring of such contaminants, especially when sludge is applied in agriculture. Microplastics, in particular, are highlighted as a growing concern due to their potential for accumulation in soil and subsequent entry into the food chain. Enhanced monitoring frameworks are expected to provide the data needed for safe sludge application and to inform future policy adjustments.

Effective sludge management requires addressing variability in sludge composition, differences in local agricultural practices, and public acceptance of its use as a fertilizer. The directive encourages Member States to adopt best practices, such as nature-based solutions, and to promote market development for recovered nutrients. Supporting innovation in treatment processes, such as anaerobic digestion combined with advanced filtration, is also emphasized to achieve higher safety and efficiency standards.

The UWWTD remains a cornerstone of EU environmental policy, ensuring the protection of water resources while advancing sustainability and public health. Its latest iteration reflects a holistic approach to urban wastewater management, integrating contemporary issues such as climate adaptation, resource recovery, and the reduction of emerging pollutants. Sewage sludge management exemplifies this approach, balancing the recovery of valuable resources with the imperative to safeguard environmental and human health. Through its comprehensive framework and forward-looking provisions, the directive aims to support Member States in achieving a resilient and sustainable wastewater management system.

### Support to the evaluation of the Sewage Sludge Directive[17]

#### Introduction and Context

The Sewage Sludge Directive (SSD) was adopted in 1986 to regulate sewage sludge use in agriculture, aiming to prevent harmful effects on soil, water, vegetation, animals, and humans. It promotes the reuse of nutrients while ensuring environmental and public health protection. Over the years, significant advancements in environmental science, public health concerns, and legislative changes have necessitated an evaluation of the SSD's effectiveness, efficiency, coherence, relevance, and EU added value.

#### Key Findings

1. Effectiveness

- Achievements: The SSD has contributed to improvements in the quality of sewage sludge used in agriculture, with usage rates ranging between 29% and 50% across

[17] European Commission, Directorate-General for Environment (2022): Support to the evaluation of the Sewage Sludge Directive; Final study report; Luxembourg: Publications Office of the European Union, 2022

EU Member States. Limit values for heavy metals in soil and sludge have generally been met, aligning with the directive's objectives.

- Challenges: Discrepancies in data collection and gaps in monitoring hinder comprehensive assessments. No substantial EU-wide data exist linking soil quality improvements directly to sludge application. Public concerns about risks, such as antibiotic resistance, continue to impact sludge usage.

2. Efficiency

- Sewage sludge management, including transport, treatment, and soil testing, incurs substantial costs. However, agricultural use of sludge is cost-effective compared to alternatives like incineration or landfilling, saving approximately €100-240 million annually.
- Administrative costs are relatively low (€77,000-€80,000/year), but monitoring pollutants of emerging concern remains inadequate, limiting full cost-benefit evaluations.

3. Coherence

- The SSD aligns well with other EU waste and water directives, though some inconsistencies in definitions and reporting cycles create inefficiencies. Harmonization of terminologies, analytical methods, and reporting requirements with related directives (e.g., Urban Waste Water Treatment Directive) is recommended.
- Lack of EU-wide criteria for the end-of-waste status of sewage sludge weakens its integration into circular economy goals.

4. Relevance

- The SSD remains relevant, particularly in addressing heavy metals in sludge and soil. However, the directive does not account for emerging pollutants like microplastics and pharmaceuticals. Updating its scope to include these concerns is critical.
- Stakeholders largely support the SSD but highlight that its limited scope restricts its effectiveness in addressing modern challenges.

5. EU Added Value

- The SSD has established a unified framework for sludge use, reducing health risks from contaminants. However, many Member States have implemented stricter regulations, raising concerns about unequal protection across the EU.
- Public perception issues and emerging contaminants threaten the directive's future relevance and EU-wide impact.

**Recommendations**

1. Enhancing Monitoring and Data Collection

- Improve data collection on sludge composition, soil quality, and pollutant levels, focusing on contaminants of emerging concern.

- Align reporting cycles and methods with related directives to ensure consistency.

2. Expanding Scope

- Update the SSD to address emerging pollutants such as microplastics, nanomaterials, and pharmaceuticals.
- Consider broader environmental and public health goals aligned with the EU Green Deal.

3. Improving Coherence

- Harmonize the SSD with other EU policies, particularly the Urban Waste Water Treatment Directive and the Waste Framework Directive.
- Establish EU-wide end-of-waste criteria for sewage sludge to streamline circular economy efforts.

4. Addressing Public Concerns

- Develop public awareness campaigns to mitigate negative perceptions of sludge use in agriculture.
- Encourage voluntary quality assurance schemes to build trust in sludge management.

5. Strengthening Implementation and Enforcement

- Ensure stricter enforcement of SSD provisions across all Member States.
- Facilitate knowledge-sharing platforms among stakeholders to promote best practices.

### Conclusion

While the SSD has been instrumental in promoting sustainable sludge management, evolving challenges and legislative gaps necessitate updates. Expanding its scope, harmonizing it with broader EU policies, and addressing public concerns are critical for its continued relevance and effectiveness in fostering environmental and public health.

## Feasibility study in support of future policy developments of the Sewage Sludge Directive[18]

### Methodology Used in the Evaluation

The report employs a combination of qualitative and quantitative analyses to assess the feasibility and impacts of different sewage sludge recovery and management methods. Key methodologies include:

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[18] Egle, L., Marschinski, R., Jones, A., Yunta Mezquita, F., Schillaci, C., Huygens, D. (2023): Feasibility study in support of future policy developments of the Sewage Sludge Directive (86/278/EEC); European Commission, Joint Research Centre; Luxembourg: Publications Office of the European Union, 2023

1. Baseline Analysis:

    - Establishes the current state of sewage sludge management in the EU, considering mass flow, nutrient content, environmental implications, and costs.

    - Uses data from Eurostat and Member States to quantify sewage sludge production and its current disposal routes.

2. Policy Option Development:

    - Explores four policy options, with two discarded early due to uncertainties in addressing identified problems.

    - Focuses on two primary options for in-depth analysis:
        - Policy Option 1 (PO1)**: Enhanced monitoring and control of sewage sludge returned to agricultural land with specific phosphorus recovery targets.
        - Policy Option 2 (PO2)**: Mandatory transformation of sewage sludge into EU-compliant phosphorus fertilisers via incineration and recovery.

3. Impact Assessment:

    - Employs models to predict the environmental, economic, and social outcomes of the two policy options.

    - Quantifies benefits such as reduced contamination, enhanced phosphorus recovery, and job creation, alongside costs like compliance expenses and infrastructure investments.

4. Cost-Benefit Analysis:

    - Incorporates direct (internal) costs for operators and external (social) costs related to environmental and health impacts.

    - Compares sewage sludge management methods, including land spreading, composting, incineration, and landfill, against policy objectives.

5. Stakeholder Input:

    - Engages Member States, industries, and agricultural representatives to gather feedback on potential policies and their practical implications.

**Main Findings of the Report**

1. Environmental and Health Protection:

    - Both PO1 and PO2 enhance safety by addressing contaminants in sewage sludge.

    - PO2 provides superior removal of organic pollutants, pathogens, and microplastics due to incineration.

2. Phosphorus Recovery and Resource Efficiency:

    - PO2 enables greater phosphorus recovery with higher agronomic efficiency through sewage sludge ash processing.

- PO1 preserves nitrogen and carbon content better but offers less phosphorus recovery potential compared to PO2.

3. Economic and Social Impacts:

- PO2 involves higher compliance costs due to incineration infrastructure but offers increased employment opportunities.
- PO1 has relatively lower costs but requires significant investments in monitoring systems.

4. Nutrient Loss and Methane Emissions:

- Both options reduce nutrient losses and methane emissions compared to the current baseline, contributing to circular economy goals.

5. Policy Trade-offs:

- PO1 aligns more with maintaining nutrient recycling for agriculture, while PO2 focuses on stricter contaminant removal at the cost of some nutrient losses (e.g., nitrogen).

6. Alignment with EU Objectives:

- Both options align with the EU's goals on zero pollution, circular economy, and sustainable resource use. PO2 is more effective in addressing long-term contamination risks and phosphorus scarcity.

The report concludes that both policy options offer feasible pathways for revising the sewage sludge directive. However, the choice between them depends on prioritizing either immediate environmental benefits (PO2) or a balanced nutrient recovery strategy (PO1). The study advocates for further research and stakeholder discussions to refine these policies.

### Screening risk assessment of organic pollutants and environmental impacts from sewage sludge management [19]

The report, developed by the Joint Research Centre (JRC) of the European Commission, investigates the environmental and health risks of sewage sludge management and its various utilization methods. It supports policy refinement under the EU Sewage Sludge Directive (SSD, 86/278/EEC). The analysis assesses the impacts of organic pollutants, resource recovery potential, and climate change implications, focusing on sustainability trade-offs.

Sewage sludge, a by-product of wastewater treatment, contains valuable nutrients like nitrogen and phosphorus but also harmful contaminants such as heavy metals, persistent

[19] Huygens D., García-Gutierrez P., Orveillon G., Schillaci C., Delre A., Orgiazzi A., Wojda P., Tonini D., Egle L., Jones A., Pistocchi A., Lugato E. (2022): Screening risk assessment of organic pollutants and environmental impacts from sewage sludge management, Study to support policy development on the Sewage Sludge Directive (86/278/EEC); European Commission, Joint Research Centre; Luxembourg: Publications Office of the European Union, 2022

organic pollutants (POPs), microplastics, and pathogens. The report evaluates the following management approaches:

1. Agricultural Use: Spreading treated or untreated sludge as a fertilizer.

2. Incineration: Burning sludge, often with energy recovery.

3. Landfilling: Disposal in engineered pits.

4. Advanced Technologies: Processes like mono-incineration for phosphorus recovery.

Recommendations for Sustainable Management

The report advocates for a balanced mix of methods tailored to local needs:

- Restrict untreated sludge in agriculture.
- Adopt advanced treatments like mono-incineration to recover nutrients while minimizing pollutants.
- Develop risk-screening methodologies and enforce quality standards for sludge use.
- Investigate innovative and cost-efficient technologies for better resource recovery and pollutant reduction.

In conclusion, while sludge management methods offer opportunities for resource recovery and climate change mitigation, significant trade-offs exist. A nuanced approach, integrating technical, environmental, and economic considerations, is crucial for sustainable sewage sludge utilization.

### Disposal and Recycling Routes for Sewage Sludge[20]

The document evaluates the environmental, economic, and regulatory aspects of various sewage sludge management methods, highlighting their impacts, challenges, and feasibility in addressing environmental and public health concerns. The recommendations for optimal management include the below elements:

1. Quality Improvement:

   - Source pollution prevention to reduce heavy metals and organic pollutants entering wastewater systems.
   - Enhance sludge treatment processes to produce safer, higher-quality sludge for reuse.

2. Regulatory and Economic Measures:

   - Harmonize and tighten regulations across jurisdictions, particularly for agricultural use.

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[20] Philippe Aubain, Alexis Gazzo, Jan Le Moux and Eric Mugnier (Arthur Andersen) and Hubert Brunet and Benoît Landrea (SEDE / EC) (2022): Disposal and Recycling Routes for Sewage Sludge; Synthesis report; European Commission, DG Environment

- Develop guarantee funds and insurance systems to address liability concerns for farmers and landowners.

3. Research and Innovation:

- Conduct studies on long-term effects of sludge application on soil and ecosystems.
- Invest in emerging technologies and standardize monitoring methods for pollutants.

4. Public Engagement:

- Promote transparency through labeling and certification of sludge quality.
- Disseminate research findings and involve stakeholders to increase acceptance of sludge recycling.

As a conclusion from the study, it has to be emphasised, that the best sludge management approach depends on balancing environmental, economic, and social considerations. Agricultural recycling offers significant benefits but requires rigorous quality control and public trust. Advanced treatment technologies and incineration are essential alternatives where land application is unsuitable. A strategic focus on pollution prevention, regulatory alignment, and technological innovation will enhance sustainable sludge management practices.

### Evaluation of the Sewage Sludge Directive[21]

#### Main Provisions of the SSD

The SSD sets binding regulations on the quality and application of sludge:

- Heavy Metal Limits: Defines maximum permissible concentrations of six heavy metals (cadmium, copper, nickel, lead, zinc, and mercury) in sludge and soil.
- Treatment Requirements: Prohibits the use of untreated sludge in agriculture unless incorporated directly into the soil under controlled conditions.
- Application Restrictions: Establishes rules for sludge use based on crop types and seasonal considerations.
- Monitoring and Reporting: Mandates Member States to monitor sludge and soil quality, keep usage records, and report to the European Commission every four years.

Member States may impose stricter controls, including additional parameters for pollutants like pathogens, organic contaminants, and microplastics.

#### Summary of the Directive on Sewage Sludge Utilization

The Council Directive 86/278/EEC, known as the Sewage Sludge Directive (SSD), was adopted in 1986 to promote the safe use of sewage sludge in agriculture while protecting human health, soil, and the broader environment. Sewage sludge, a byproduct of

[21] Commission Staff Working Document; Evaluation of the Council Directive 86/278/EEC of 12 June 1986 on the protection of the environment, and in particular of the soil, when sewage sludge is used in agriculture SWD(2023) 158 final

wastewater treatment, contains valuable nutrients and organic matter but also potentially harmful contaminants like heavy metals and pathogens. The Directive aims to regulate agricultural use to mitigate risks while encouraging nutrient recovery, aligning with the European Union's broader goals of waste recovery and circular economy.

The Directive focuses exclusively on sludge used in agriculture and excludes other potential uses, such as energy recovery or land reclamation. Its provisions set minimum harmonized standards across Member States while allowing stricter national regulations. The evaluation of the SSD covered its entire lifespan, emphasizing data from 2007–2018.

### Evolution and Context

Since the Directive's adoption, the sludge management sector has advanced significantly:

1. Policy Shifts: Integration with EU initiatives like the Circular Economy Action Plan and the European Green Deal underscores the role of sludge in sustainable agriculture.
2. Technological Advances: Innovations in wastewater treatment have improved sludge quality, facilitating its safer application.
3. Market and Legislative Developments: The Urban Wastewater Treatment Directive (1991) spurred increased sludge production, necessitating updated management strategies. Concurrently, Member States have introduced complementary national rules.

### Implementation Challenges and Variations

Implementation varied across Member States:

- Many adopted stricter heavy metal limits or outright banned sludge use in agriculture, as seen in regions of Austria and Germany.
- Data gaps and inconsistencies, particularly from Eastern Member States, complicated comprehensive evaluations.
- Competing uses for sludge, such as energy recovery, and societal perceptions about safety also influenced implementation.

### Conclusion and broader Implications

The Directive supports nutrient recycling, reduces reliance on chemical fertilizers, and aligns with EU waste policies emphasizing recovery over disposal. However, it has faced criticism for not addressing emerging contaminants or setting clear objectives for soil quality improvements.

The SSD has played a foundational role in establishing a harmonized framework for sewage sludge use in agriculture. Despite data limitations and evolving environmental priorities, it remains central to balancing waste recovery and environmental protection within the EU. Future updates to the Directive should address gaps in data, harmonize criteria, and incorporate new scientific insights into contaminants and sludge applications.

### Recommendations from the Evaluation

The evaluation of the Sewage Sludge Directive (SSD) identified several areas for improvement and provided recommendations to address current challenges, align with updated EU policies, and enhance its effectiveness. These include:

1. Modernizing Pollutant Standards

- Update the list of regulated pollutants to reflect emerging contaminants such as microplastics, pharmaceuticals, and other hazardous substances not covered in the original Directive.
- Set stricter and harmonized limits for heavy metals and additional contaminants to ensure high levels of environmental and health protection.

2. Strengthening Data Collection and Monitoring
   - Improve data consistency and quality across Member States, particularly in Eastern Europe, to ensure comprehensive and comparable datasets.
   - Require systematic reporting of soil quality where sewage sludge is applied, correlating it with sludge use to monitor impacts more effectively.
3. Aligning with Circular Economy Goals
   - Promote nutrient recovery technologies, such as phosphorus recovery, to reduce dependency on non-renewable resources and enhance resource efficiency.
   - Encourage innovative uses of treated sludge beyond agriculture, including industrial applications and energy recovery, while maintaining safety.
4. Harmonizing Practices Across Member States
   - Establish more uniform criteria and standards for sludge treatment and application to reduce discrepancies among national regulations.
   - Encourage knowledge exchange and best practice sharing, particularly regarding stricter national requirements and innovative sludge management strategies.
5. Addressing Public Perception and Stakeholder Engagement
   - Implement targeted communication strategies to improve public and farmer confidence in sludge use, addressing concerns over safety and odor.
   - Involve stakeholders, including farmers, food industries, and NGOs, in revising policies to build trust and ensure acceptance.
6. Improving Enforcement and Compliance
   - Strengthen enforcement mechanisms, including fines and penalties, to ensure consistent compliance with the Directive's requirements.
   - Support capacity-building initiatives for national authorities to monitor and enforce sludge management practices effectively.
7. Encouraging Alternative Treatment Options
   - Foster the adoption of advanced treatment technologies, such as anaerobic digestion, composting, and thermal processing, to improve sludge quality and diversify end-uses.
   - Support research into emerging treatment methods and their integration into sludge management frameworks.

## 3.3 Sludge quality and quantity

The amount and the quality of sludge greatly depends on the coverage of sewage treatment and the technology applied in the treatment process. Whereas the geographical coverage of sewage treatment can be relatively easily defined, the persons equivalent (PE) coverage has got several elements that influences the amount of sludge produced. Considering the most important factor, the existence / coverage of sewers and treatment plants, according to the studies recently published[22], Danube Region countries face different challenges in this regard: whereas the coverage of the tertiary sewage treatment in Austria and Germany is reaching almost 100%, in some of the central areas of the region (Czech Republic, Hungary and Slovenia) the coverage of tertiary treatment is between 70-80%, in Croatia and Slovakia secondary treatment prevails with a coverage of 60-75%. In the lower Danube Region, due to the developments of the last decade treatment coverage grew up to 50% in Romania and 75% in Bulgaria, with considerable shares of secondary treatment due to operation of the old WWTPs. In Serbia and Bosnia and Herzegovina tertiary treatment is negligible, 10-20% of the population is connected to WWTPs with secondary treatment; the situation is similar in Montenegro, the Ukraine and Moldova.  In these countries many times sewage is collected at least in the central part of larger agglomerations, but their proper treatment is not solved.

Considering the changes in treatment level, it can be seen from the data that while Austria and Germany developed their treatment plants to the tertiary level by 2005, countries in the central part of the Danube Region are somewhere in the middle or at the end of this process in parallel with increasing coverage. Downstream countries with lower tertiary treatment coverage are expected to experience similar processes, coupled with their ongoing national efforts to cope with the most urgent sewage treatment problems (e.g. Belgrade, Sarajevo); in these cases the financing of the investments is many times aided by international financing institutions, such as the EIB, EBRD or the WB.

The settlement systems of the various regions may put considerable burden to further develop the sewage treatment systems. Whereas the solution for large agglomerations is relatively simple and feasible, in small settlements / agglomerations, and especially with scattered structure as in many lower and central Danube Region countries, is rather problematic concerning safe technologies on acceptable investment and operational costs.

The changing treatment level, besides the specific technological solutions, has great influence on the quality of sludge. This concerns pathogens, nutrients, other organic materials, heavy metals equally, thus the technologies influence greatly not only the amount of sludge produced but also its quality and the potentials for various recovery techniques. The reconstruction of the sewage systems has another important element concerning sludge quality, that is rainwater management. In the older common systems, the rainwater

[22] Pistocchi, A., Husemann, J., Masi, F., Nanu, C., (editors) (2020): Wastewater treatment in the Danube region: opportunities and challenges; Joint Research Centre (JRC) – Science Policy Report, Luxembourg: Publications Office of the European Union, 2020
ICPDR (2020): Wastewater management issues; Updated summary of the Tour de Table discussion held at the 31st PM EG Meeting
EEA (quoted 20.11.2020): Urban waste water treatment in Europe; https://www.eea.europa.eu/data-and-maps/indicators/urban-waste-water-treatment/urban-waste-water-treatment-assessment-5

runoff greatly influences the efficiency of the treatment technology, and, at the same time, introduces pollutants that are typical for runoff such as heavy metals. The development of the sewage systems, thus, many times includes the construction of independent sewage collectors, changing/improving sludge quality considerably over time.

Another aspect of sludge production besides coverage and technologies is the number of inhabitants actually connected to the systems. This number changes over time; the decrease of the population in general and especially in the rural areas is a significant problem in the Bosnia and Herzegovina and Serbia. In other downstream and central countries this problem exists to a smaller extent and many times is relevant in the case of the smaller rural settlements, requiring special techniques for sewage and sludge treatment and recovery. In the upstream countries the population is ageing however can be considered steady due to other socio-economic processes.

The aspect of the quality of economies and the overall environmental awareness in consumption influence the quality of sludge. It has been reported[23] that the quality of waste water and consequently sludge is influenced by factors, such as the type and urban form of the agglomeration, the typically used plumbing materials, presence and type of industrial plants, the share of commercial activities, traffic density, street cleaning and the maintenance of the sewage collection and treatment systems. Measurements show different sources being dominant at various environmental loads (1. Table: Potential toxic element load in the percentage of the total from different sources, estimates):

| | Domestic | Commercial | Industrial |
|---|---|---|---|
| **Zn** | 30-50 | 5-35 | 10-20 |
| **Cu** | 30-75 | 3-20 | 4-6 |
| **Ni** | 10-50 | 30 | 10-20 |
| **Cd** | 20-40 | 30-60 | 3-40 |
| **Pb** | 30-80 | 2-20 | 30 |
| **Cr** | 2-20 | 35-60 | 2-20 |
| **Hg** | 4-5 | 50-60 | 1-5 |

*1. Table: Potential toxic element load in the percentage of the total from different sources, estimates*
*Source: ICON, 2001*

As it can be seen from the table, there are wide variations, however, commercial sources seem to have significant impact on the overall quality of sewage, and in the case of the presented toxic metals, the quality of sludge too. Given rising incomes in the middle- and low-income countries of the region and a shift towards the service and commercial sectors it can be estimated that the toxic metal load of sludge will increase.

There have been several pollutants in sewage and sludge, some of them giving good examples for the behaviour of the chemicals present in the process. A study on the many times carcinogen polycyclic aromatic hydrocarbons (PAHs) found[24] that the occurrence of

[23] ICON (2001): Pollutants in Urban Waste Water and Sewage Sludge; Final Report for DG Environment; https://ec.europa.eu/environment/archives/waste/sludge/pdf/sludge_pollutants_7.pdf
[24] Yhang, X. (2019): The fate and enhanced removal of polycyclic aromatic hydrocarbons in wastewater and sludge treatment system: A review; in Journal Critical Reviews in Environmental

PAHs greatly depends on the industrialisation and the applied environmental standards of the given location. The study revealed that while low molecular weight PAHs are degraded in the sewage treatment process, high molecular weight PAHs are absorbed in the sludge that can be partly eliminated through anaerobic digestion, incineration giving a full solution to the problem. This example shows the complexity and contaminant specificity of the sludge pollutant issue.

In the past decade there have been widespread discussions on pollutants that had not been studied in depth due to their rare occurrence. In the last few years more and more scientific evidences have been gathered on the micropollutant content of sewage and sludge, micro-plastics, pharmaceuticals, certain organic compound are found in growing quantities in sludge. Many of these micropollutants cannot be removed during the traditional waste water treatment processes, a great proportion of them is absorbed in sludge. These materials can later react with others, for example due to sunlight, can turn bioactive and bioaccumulate causing growing threat to soils and waters[25] and the living environments.

## 3.4 Managerial considerations

### Financial issues

It has been indicated during the above discussions and data that the cost and the generated income from sludge management greatly depends on the applied technology and recovery technique. From the financial and economic feasibility point of view each solution has its advantage and the applicability of a specific technique depends on several factors that are embedded in the wider socio-economic environment and the local / regional limits of the environment.

The share of the investment in sludge management is relatively high within the sewage treatment system. It has been revealed in several reports[26] on investments that even a more simple sludge systems built for agricultural recovery can constitute the 30% of the overall investment costs; in case of applying more advanced and technology intensive technologies the share of the costs can be as high 50%. The range in-between cost can be estimated as rather high; the first and most important factor is specific technology applied, other costs are influenced by several factors, many of them being the function of local and national legislations and the given socio-economic environment:

- Labour cost level
- Energy price level
- Land price level
- Transport cost

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Science and Technology; Volume 49, 2019 - Issue 16; https://www.tandfonline.com/doi/full/10.1080/10643389.2019.1579619?src=recsys

[25] Hossain, A. (2016) / Das, S. et al. (2016): Micropollutants in Wastewater: Fate and Removal Processes; INTECH; https://www.intechopen.com/books/physico-chemical-wastewater-treatment-and-resource-recovery/micropollutants-in-wastewater-fate-and-removal-processes

[26] Aswekar, P. et al. (2017): Feasibility Study of Energy Recovery by Incineration – A Case Study of the Triangle Wastewater Treatment Plant; Master project; Nicholas School of the Environment of Duke University

- Cost of waste disposal

The figures representing the sewage treatment investments of the Czech Republic, Hungary, Romania and Slovakia published in the report of the European Court of Auditors on the EU financed urban waste water plants in the Danube Basin show that the unit cost of the investment in treatment plants can be estimated around 250EUR/PE. It has been also reported that sludge treatment facilities, including dewatering and composting can be sum up to the 30-35% of the total investment costs. This means that on average 80-85EUR/PE cost can be calculated for sludge management within WWTPs and extra cost occur for the final recovery, either in landfills, agriculture or incinerators.

Concerning the cost of different treatment and recovery techniques it can be seen from the studies prepared for the Sludge Treatment and Recovery Strategy (2014-2023) of Hungary that, in the given Hungarian economic environment, economies of scale and technology greatly influence the unit costs of the investment (2. Table: Unit costs of investment in sludge management according to certain technologies and sizes, treated sludge in EUR per dry matter tonne):

| | 2 000-10 000 PE | 10 000-50 000 PE | 50 000-200 000 PE |
|---|---|---|---|
| **Technology 1.** | 4 509 | 2 940 | 1 603 |
| **Technology 2.** | | 2 292 | 1 959 |
| **Technology 3.** | 7 057 | 5 045 | 3 701 |

*2. Table: Unit costs of investment in sludge management according to certain technologies and sizes, treated sludge in EUR per dry matter tonne*

*Source: Sludge Treatment and Recovery Strategy (2014-2023), Hungary; extract from option analysis*

*Technology 1.: Pre-treated (water c.: 15-30%), aerobe stabilisation, compost for agricultural use complying with pollution limits*

*Technology 2.: Pre-treated (water c.: 15-30%), anaerobe stabilisation, compost for agricultural use complying with pollution limits*

*Technology 3.: Pre-treated (water c.: 40-60%), aerobe stabilisation, energy recovery*

As it can be seen in the above table, large plants perform considerably better in terms of cost-efficiency and the less costly solution is relatively simple dewatering, aerobe stabilisation and composting, still providing fair environmental performance. In this process thresholds for nowadays contaminant content can be fulfilled and compost can be an important matter for agricultural use. In general, anaerobe treatment is by 20% more expensive, however energy recovery is possible during digestion. The incineration of the sludge is around twice as expensive as other technologies, but here considerable energy can be produced. It is estimated the payback period of the establishment of a modern incinerating sludge recovery system is around 6-9 years, given sewage fees and market prices, typical in the upstream countries. In contrast, the payback period of composting and agricultural use is around 2-4 years depending on the applied technology and the economic environment.

Incineration is considered the most expensive way of recovery where the removal of phosphorous and other nutrients ads to the investment and operational costs. Poland operates a relatively large number of incinerators, the investment costs of which are presented for indication in the below table (3. Table: Planned incinerators' capacities and estimated investment costs in Poland (potential co-burning sludge)):

| City | Capacity (t/year) | Number of incinerators | Total cost (EUR) |
|---|---|---|---|
| **Bialystok** | 120 000 | 1 | 80 000 000 |
| **Bydgoszcz & Torun** | 180 000 | 2 | 96 000 000 |
| **Konin** | 94 000 | 1 | 71 000 000 |
| **Krakow** | 220 000 | 2 | 156 000 000 |
| **Poznan** | 210 000 | 2 | 177 000 000 |
| **Szczecin** | 150 000 | 2 | 130 000 000 |

*3. Table: Planned incinerators' capacities and estimated investment costs in Poland (potential co-burning sludge) Source: Cyranka et al. 2016*[27]

The dominant part of operational costs of sludge management, similarly to investment costs, can be linked to the operational costs of sewage treatment plants. It is estimated[28] that 50% of the total annual costs (investment and operation) can be attributed to operations, and around 15-50% of the overall operational costs are attributed to sludge management. These costs greatly depend on

- the size of the treatment plant,
- national regulations for the disposal of organic materials and
- local conditions and market price conditions.

The scale of economies here is also an important issue; it was revealed that in small size plants (less than 10 000 PE) labour costs can make up much as 50% of the total operating cost of sludge management systems, whereas in large plants the share of the labour cost diminishes to 15%. Maintenance costs greatly depend on the technologies used as the maintenance of civil construction require an expenditure of around the 1-2% of the investment cost annually, the maintenance of mechanical and electrical equipment can be as high as 6% of the investment cost every year. Concerning energy, on average the 8% of all energy costs can be associated with sludge treatment at the WWTPs (in case of sludge airing and digestion).

The overall feasibility of sludge management systems, as seen above, can be influenced by many factors that greatly depend on the investment and operational costs of the applied technology, the overall economic environment, the size of the operations and marketability of "products" (compost, energy, fly ash, etc.). The situation is rather different in these regards in the Danube Region, as the economic environment in the upstream countries is different from the central ones and the downstream ones. In general, it can be well assumed that external environmental costs are more considered in the upstream economies with high revenues, high energy and labour costs and applying technology intensive technologies. Here consumers' behaviour is more environmentally conscious. Sludge products after procession matching strict environmental standards are well tradeable as raw materials for

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[27] Cyranka et al. (2016): Municipal Waste-to-Energy plants in Poland – current projects; E3S Web of Conferences 10; https://www.researchgate.net/publication/309217014_Municipal_Waste-to-Energy_plants_in_Poland_-_current_projects

[28] Wendland, A. (2005): Operation Costs of Wastewater Treatment Plants; educational paper / Hamburg Public Sewage Company

sectors. As a result, thermal / energetic recovery of sludge becomes feasible. Thus, in these countries, in accordance with the principles of circular economy, private enterprises are entering the market for secondary products and processing technologies after the investment of the public sector in the treatment and recovery of sludge.

In most of the other Danube Region countries, agricultural recovery of composted sludge became the dominant solution due to the facts that it requires relatively small investment, it's less technology- and more labour-intensive (lower labour costs), land-, transport- and energy prices are relatively low, and also because with cautious applications threshold values for pollutants can be observed. The situation is, however, somewhat changing with rapidly increasing energy and transport costs and growing wages especially in the central and downstream countries. Still, investments in sludge management are financed by public sources, as countries lack appropriate financial resources even for the installation of the less expensive recovery technologies. Also, loans make up a great part of the investments, the World Bank – through its Danube Water Programme together with IAWD – the European Investment Bank and the EBRD being active in this sector mostly in the downstream and non-EU countries; a joint programme of the various international financing institutions in financial investments in the sector is, for example, the Infrastructure Project Facility of the Western Balkans Investment Facility (WBIF).

### The strategic decision on sludge management

There a number of paper reviewing and evaluating the diverse business models for managing sewage sludge through resource recovery and reuse, emphasizing their alignment with circular economy principles. They highlight the increasing need for innovative sludge management solutions due to regulatory restrictions on traditional disposal methods like landfilling. The studies usually identify four primary categories of resource recovery: organic fertilizers, crop nutrients, energy, and hybrid models combining these elements. Case studies of existing business models provide a basis for analysing technical, financial, and environmental feasibility, ensuring that recommendations are grounded in practical implementation rather than theoretical constructs[29].

The models are tailored to specific recovery objectives, each with unique approaches, strengths, and limitations. For organic fertilizer production, models utilize processes like dewatering, stabilization, and composting to transform sludge into valuable biosolids. This approach supports sustainable agriculture but is constrained by contamination risks from heavy metals and pathogens.

Phosphorus recovery is another focal point, with models leveraging either incinerated sludge ash or anaerobic sludge digestate. While phosphorus recovery addresses the depletion of natural phosphate reserves, its financial viability remains a challenge due to competition with cheaper mined alternatives.

Energy recovery models include anaerobic digestion, incineration, and advanced technologies like pyrolysis and gasification. Anaerobic digestion is a widely adopted, cost-effective method, yielding biogas and digestate. In contrast, incineration offers high energy

[29] A. Taron, S. Singh, P. Drechsel, C. Ravishankar and A. Ulrich (2023): Sewage Sludge: A Review of Business Models for Resource Recovery and Reuse; Resource Recovery & Reuse Series 23; International Water Management Institute (IWMI), 2023

outputs but generates substantial emissions and ash, necessitating rigorous pollution control. Emerging methods like pyrolysis and gasification hold promise for reducing environmental impacts and producing versatile outputs like biochar and syngas but face high initial costs and technological complexity.

Hybrid models integrate multiple recovery pathways, such as combining energy production with phosphorus recovery. These models maximize resource utilization but require advanced infrastructure and significant capital investment, limiting their applicability in low-income regions.

It can be concluded that resource recovery from sewage sludge is essential for sustainable waste management and circular economy objectives. Business models tailored to local contexts, regulatory frameworks, and market dynamics are critical for success. The study underscores the importance of policy incentives and technological advancements in scaling resource recovery practices. However, it shall be highlighted that significant challenges, including high operational costs, public resistance to waste-derived products, and the need for stringent quality standards. All in all, a collaborative approach is recommend involving governments, private entities, and research institutions to overcome these barriers and unlock the full potential of resource recovery from sewage sludge.

# 4 Sludge treatment in the Danube Region countries – an overview

## 4.1 Country overviews

The source of the data presented in this section, if not stated otherwise, is the data made available by the EUROSTAT on "Sewage sludge production and disposal" at https://ec.europa.eu/eurostat/databrowser/view/env_ww_spd/default/table?lang=en in the mid of September, 2024; note that in the case of some countries data were not made available in the dataset; in the figures the most recent data from 2018 to 2022 is presented as shown in the supporting tables. For missing values, in some cases averages were considered.

In the figures and tables, the terminology of EUROSTAT is used according to the Data Collection Manual for the OECD/Eurostat Joint Questionnaire on Inland Waters (2014.):

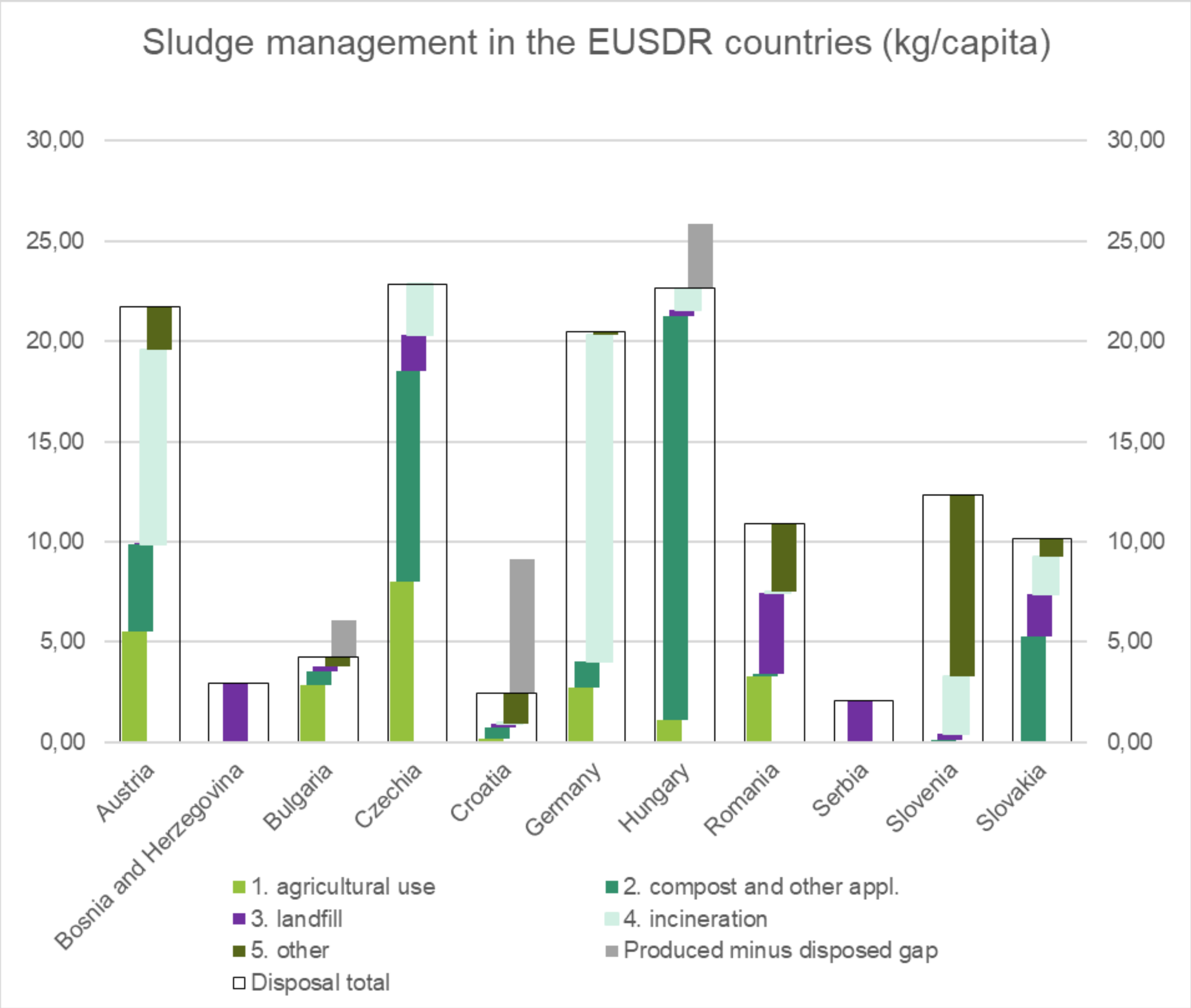
- Agricultural use: all use of sewage sludge as fertiliser on arable land or pastures, the method of application being of no importance.
- Compost and other application: all application of sewage sludge after mixing with other organic material and composting in parks, horticulture etc.
- Landfill: all quantities of sludge which are disposed of in tips, landfill areas or special depot sites without any useful function.
- Incineration: all sludge that is disposed of by direct incineration or after mixing with other waste.

The definitions above are useable although not specify the pre-treatment used or the application of the disposed sludge causing a gap in information and therefore in understanding fully how the disposal of sludge is completed for example in agricultural use and in the compost and other applications categories. Similarly, there is no data found regarding the quality of sludge, countries have no obligation to report it therefore no country or region specific tendencies can be determined, only general statements can be made.

As in some cases data discrepancies were found, thus gap between sludge "produced" and "disposed of" is calculated for each country; the amount of sludge produced equals to "gap" + "disposal". There is only limited, sometimes oral information on the amounts falling in the "gap" category, thus the management of this amount is "unknown" or partly can be considered in the export-import activities, on which, also, there have been no reliable data found with a Danube basin coverage (see discussion on export-import issues at the end of this section).

Besides the above general remarks, it can be stated that due to various reasons, such as improper and/or varying monitoring, data collection, reporting and management processes, overall data quality on Danube Basin level is relatively low and many times still smaller gaps and discrepancies can be found. Here we present data as issued by EUROSTAT, noting that clarification of the many issues arising from the above situation is possible only with the active co-operation of national authorities and professional bodies.

All data presented in the above figure represent the latest available data published by EUROSTAT for each country as shown in the section on national data respectively. In the case of Moldova, Montenegro and Ukraine there were no sufficient numeric data found to be included in the figure. In some cases, where specific annual data-gaps occurred the averages of the closest years were applied to present comprehensive timeseries. A major result of the assessment is shown in the below figure for better understanding:




*1. Figure: Sludge management in the EUSDR countries – annual averages, 2019-2022*

Comparing the data in the previous figure with the results of the 2020 study[30], it can be concluded that the difference between the amount of sewage sludge produced and

[30] EUSDR (Trenecon Ltd.) (2020): Preparatory study on sewage sludge management in Danube Region, November 30. 2020

disposed of (gap) has decreased in recent years. Among the treatment methods, the rate of landfill decreased. The agricultural utilization rate remained at a stable high level in Austria, Bulgaria and the Czech Republic, however, it decreased in Croatia. In both periods, composting and other application of sewage sludge are high in Hungary and the Czech Republic. Incineration remained the dominant treatment method in Germany and Austria, with rates in these countries being exceptionally high compared to other countries.

### 4.1.1 Austria

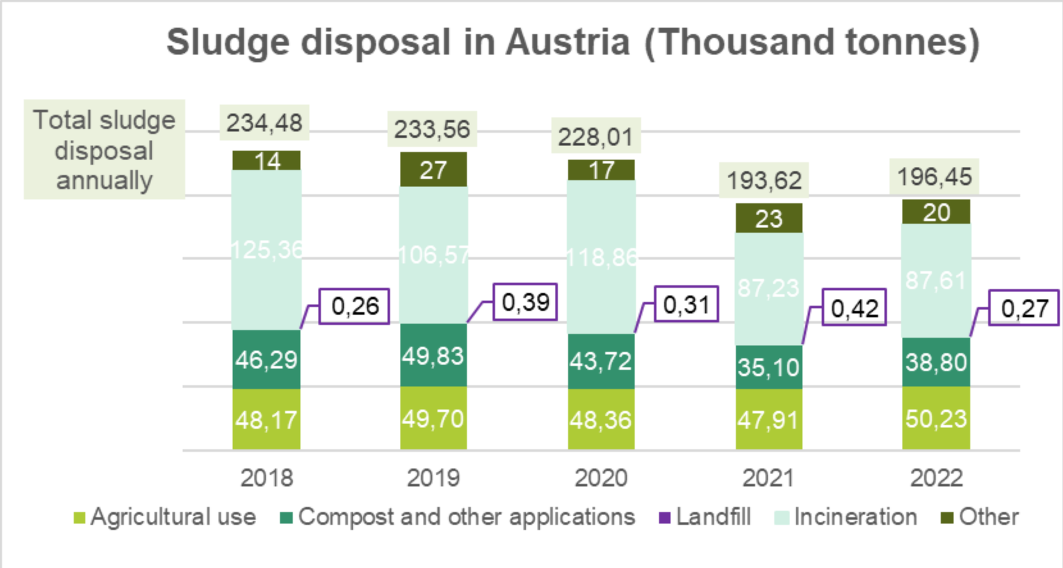
The production and disposal methods and their distribution are illustrated in the tables and the diagram below for the period under review.

| | 2018 | 2019 | 2020 | 2021 | 2022 |
|---|---|---|---|---|---|
| **Sludge production (Thousand tonnes)** | | | | | |
| **Total** | 234.48 | 233.56 | 228.01 | 193.62 | 196.45 |
| **Sludge disposal (Thousand tonnes)** | | | | | |
| **Total** | 234.48 | 233.56 | 228.01 | 193.62 | 196.45 |
| **Agricultural use** | 48.17 | 49.70 | 48.36 | 47.91 | 50.23 |
| **Compost and other applications** | 46.29 | 49.83 | 43.72 | 35.10 | 38.80 |
| **Landfill** | 0.26 | 0.39 | 0.31 | 0.42 | 0.27 |
| **Incineration** | 125.36 | 106.57 | 118.86 | 87.23 | 87.61 |
| **Other** | 14 | 27 | 17 | 23 | 20 |
| **Produced minus disposed sludge (Thousand tonnes)** | | | | | |
| **Gap** | 0 | 0 | 0 | 0 | 0 |

*4. Table: Sewage sludge production and disposal in Austria, tonnes*

| | 2018 | 2019 | 2020 | 2021 | 2022 |
|---|---|---|---|---|---|
| **Sludge production (Thousand tonnes)** | | | | | |
| **Total** | 234.48 | 233.56 | 228.01 | 193.62 | 196.45 |
| **Sludge disposal (percentage)** | | | | | |
| **Total** | 100% | 100% | 100% | 100% | 100% |
| **Agricultural use** | 21% | 21% | 21% | 21% | 26% |
| **Compost and other applications** | 20% | 20% | 21% | 19% | 20% |
| **Landfill** | 0% | 0% | 0% | 0% | 0% |
| **Incineration** | 53% | 53% | 46% | 52% | 45% |
| **Other** | 6% | 6% | 12% | 7% | 10% |
| **Produced minus disposed sludge (percentage)** | | | | | |
| **Gap** | 0% | 0% | 0% | 0% | 0% |

*5. Table: Sewage sludge production and disposal in Austria, percentages*




*2. Figure: Sewage sludge disposal in Austria*

Compared to 2018, the total amount of sewage sludge produced has decreased by 16%. The division between the methods of use and disposal has not changed significantly in the recent years, there are some minor changes in regards to agricultural use (minor increase) and incineration (minor decrease).

The table shows that 100% of the produced sewage sludge is disposed of in each of the examined years. Austria incinerates most of the produced sludge, focusing on energetic utilisation; according to additional information, the remaining ashes are further process for nutrient recovery. Still significant amount is directly used in agriculture and only a small amount is of sludge, approximately 250 tons, is landfilled. Especially regarding the former solution some progress may be desirable.

### 4.1.2 Bosnia and Herzegovina

According to EUROSTAT data Bosnia and Herzegovina produces 9.5 thousand tons of sewage sludge every year, 100% of which is landfilled.  This indicates progress, as in previous years (2016-2017) there was a significant difference between the amounts of produced and disposed sludge, i.e. considerable disposal gap was reported. The landfilling of sludge, however, is not considered a resource efficient solution.

| | 2018 | 2019 | 2020* | 2021* | 2022* |
|---|---|---|---|---|---|
| **Sludge production (Thousand tonnes)** | | | | | |
| **Total** | 9.50 | 9.50 | 9.50 | 9.50 | 9.50 |
| **Sludge disposal (Thousand tonnes)** | | | | | |
| **Total** | 9.50 | 9.50 | 9.50 | 9.50 | 9.50 |
| **Agricultural use** | 0 | 0 | 0 | 0 | 0 |
| **Compost and other applications** | 0 | 0 | 0 | 0 | 0 |
| **Landfill** | 9.50 | 9.50 | 9.50 | 9.50 | 9.50 |
| **Incineration** | 0 | 0 | 0 | 0 | 0 |

| | 2018 | 2019 | 2020* | 2021* | 2022* |
|---|---|---|---|---|---|
| **Sludge production (Thousand tonnes)** | | | | | |
| **Other** | 0 | 0 | 0 | 0 | 0 |
| **Produced minus disposed sludge (Thousand tonnes)** | | | | | |
| **Gap** | 0 | 0 | 0 | 0 | 0 |

*6. Table: Sewage sludge production and disposal in Bosnia and Herzegovina, tonnes*
*(*there is no data for 2020, 2021, 2022, so data estimated on the basis of previous years were used)*

### 4.1.3 Bulgaria

In the diagram above, it can be seen that the amount of sewage sludge produced has decreased compared to 2018. The time series shows a 15-30% gap between the amounts of sewage sludge produced and disposed of. The management of this amount is "unknown".

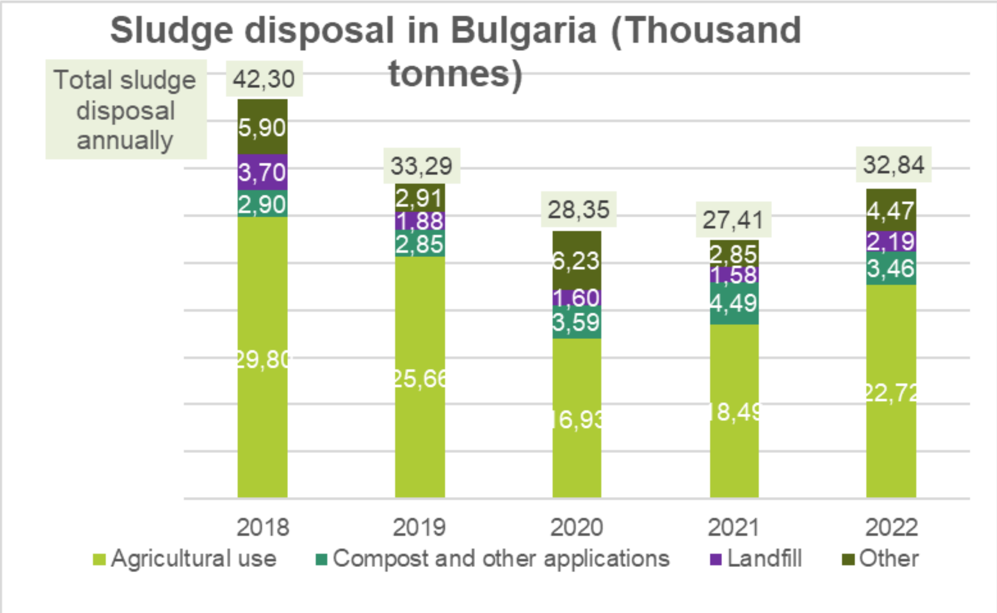
| | 2018 | 2019 | 2020 | 2021 | 2022* |
|---|---|---|---|---|---|
| **Sludge production (Thousand tonnes)** | | | | | |
| **Total** | 53.1 | 44.43 | 33.53 | 39.19 | 42.56 |
| **Sludge disposal (Thousand tonnes)** | | | | | |
| **Total** | 42.3 | 33.29 | 28.35 | 27.41 | 32.84 |
| **Agricultural use** | 29.8 | 25.66 | 16.93 | 18.49 | 22.72 |
| **Compost and other applications** | 2.9 | 2.85 | 3.59 | 4.49 | 3.46 |
| **Landfill** | 3.7 | 1.88 | 1.6 | 1.58 | 2.19 |
| **Incineration** | 0 | 0 | 0 | 0 | 0 |
| **Other** | 5.9 | 2.91 | 6.23 | 2.85 | 4.47 |
| **Produced minus disposed sludge (Thousand tonnes)** | | | | | |
| **Gap** | 10.80 | 11.14 | 5.18 | 11.78 | 9.73 |

*7. Table: Sewage sludge production and disposal in Bulgaria, tonnes*
*(*the data for 2022 were not available in the EUROSTAT database when the document was prepared, so the average of previous years was taken into account for this year.)*

| | 2018 | 2019 | 2020 | 2021 | 2022* |
|---|---|---|---|---|---|
| **Sludge production (Thousand tonnes)** | | | | | |
| **Total** | 53.1 | 44.43 | 33.53 | 39.19 | 42.56 |
| **Sludge disposal (percentage)** | | | | | |
| **Total** | 80% | 75% | 85% | 70% | 77% |
| **Agricultural use** | 56% | 58% | 50% | 47% | 53% |
| **Compost and other applications** | 5% | 6% | 11% | 11% | 8% |
| **Landfill** | 7% | 4% | 5% | 4% | 5% |
| **Incineration** | 0% | 0% | 0% | 0% | 0% |
| **Other** | 11% | 7% | 19% | 7% | 11% |
| **Produced minus disposed sludge (percentage)** | | | | | |
| **Gap** | 20% | 25% | 15% | 30% | 23% |

*8. Table: Sewage sludge production and disposal in Bulgaria, percentage*

*(*the data for 2022 were not available in the EUROSTAT database when the document was prepared, so the average of previous years was taken into account for this year.)*




*3. Figure: Sewage sludge disposal in Bulgaria*

EUROSTAT data showed that sewage sludge is mostly used in agriculture (more than 50%), and minor amounts are landfilled and used for composting; other applications also make up a considerable part of the total sludge treated. The amount of sludge landfilled has decreased, and the rate of utilization as compost has increased. Based on the data, Bulgaria does not opt for energy utilisation.

### 4.1.4 Czech Republic

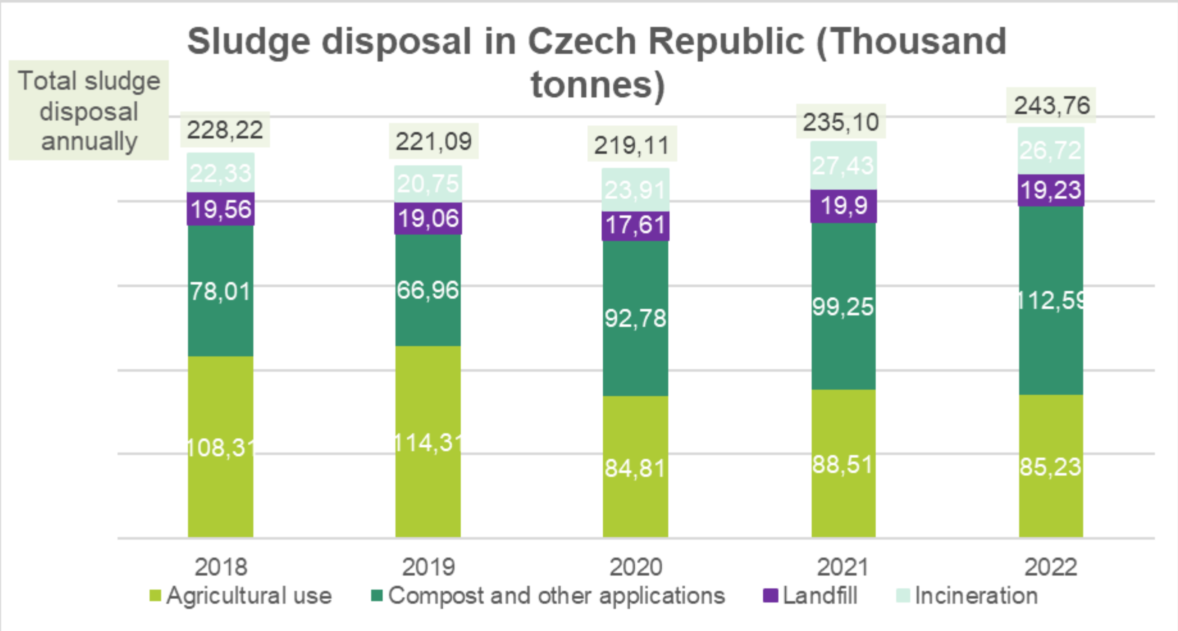
Compared to 2018, the amount of sewage sludge generated in 2022 increased by 15 540 tonnes, but the entire amount was disposed of every year.

| | 2018 | 2019 | 2020 | 2021 | 2022 |
|---|---|---|---|---|---|
| **Sludge production (Thousand tonnes)** | | | | | |
| **Total** | 228.22 | 221.09 | 219.11 | 235.1 | 243.76 |
| **Sludge disposal (Thousand tonnes)** | | | | | |
| **Total** | 228.22 | 221.09 | 219.11 | 235.1 | 243.76 |
| **Agricultural use** | 108.31 | 114.31 | 84.81 | 88.51 | 85.23 |
| **Compost and other applications** | 78.01 | 66.96 | 92.78 | 99.25 | 112.59 |
| **Landfill** | 19.56 | 19.06 | 17.61 | 19.9 | 19.23 |
| **Incineration** | 22.33 | 20.75 | 23.91 | 27.43 | 26.72 |
| **Other** | 0 | 0 | 0 | 0 | 0 |
| **Produced minus disposed sludge (Thousand tonnes)** | | | | | |
| **Gap** | 0 | 0 | 0 | 0 | 0 |

*9. Table Sewage sludge production and disposal in the Czech Republic, tonnes*

| | 2018 | 2019 | 2020 | 2021 | 2022 |
|---|---|---|---|---|---|
| Sludge production (Thousand tonnes) | | | | | |
| **Total** | 228.22 | 221.09 | 219.11 | 235.1 | 243.76 |
| Sludge disposal (percentage) | | | | | |
| **Total** | 100% | 100% | 100% | 100% | 100% |
| **Agricultural use** | 47% | 52% | 39% | 38% | 35% |
| **Compost and other applications** | 34% | 30% | 42% | 42% | 46% |
| **Landfill** | 9% | 9% | 8% | 8% | 8% |
| **Incineration** | 10% | 9% | 11% | 12% | 11% |
| **Other** | 0% | 0% | 0% | 0% | 0% |
| Produced minus disposed sludge (percentage) | | | | | |
| **Gap** | 0% | 0% | 0% | 0% | 0% |

*10. Table Sewage sludge production and disposal in the Czech Republic, percentage*




*4. Figure: Sewage sludge disposal in the Czech Republic*

As the figure shows above in 2018, nearly 50% of sewage sludge was used in agriculture, while in 2022 this number decreased to 35%. The composted quantity increased by 10% during the examined time; this shows that the more resource efficient composting techniques were gaining impetus against direct agricultural use. The amount of sewage sludge entering the landfill is fairly constant (around 8% of the total sludge disposal), as well the incinerated quantity is around 10% annually.

### 4.1.5 Croatia

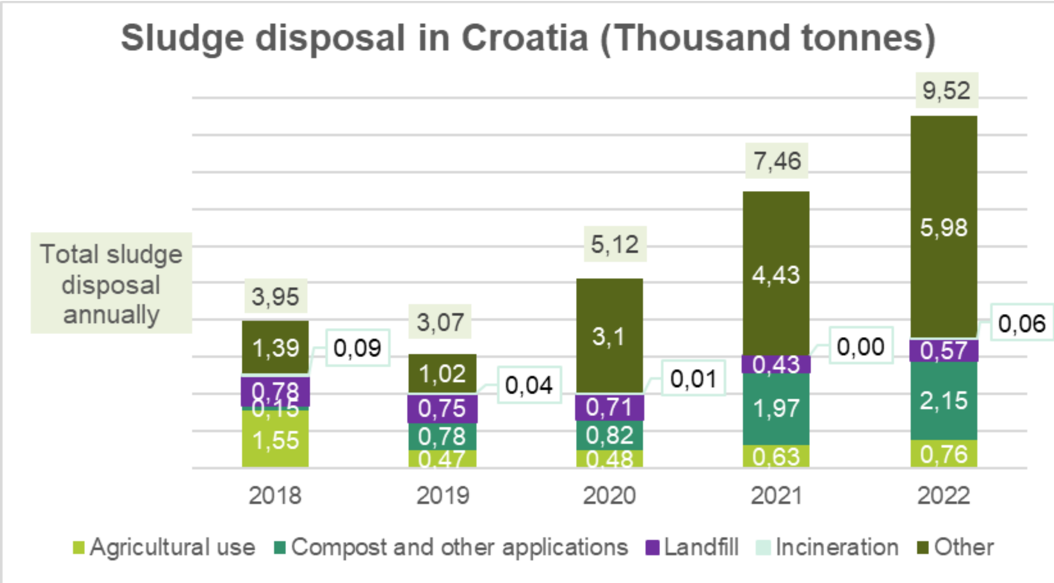
Based on the EUROSTAT data, sewage sludge production increased considerably in the recent years, along with considerable gap between the amounts of total production and total disposal.

| | 2018 | 2019 | 2020 | 2021 | 2022 |
|---|---|---|---|---|---|
| **Sludge production (Thousand tonnes)** | | | | | |
| **Total** | 19.23 | 20.65 | 21.71 | 27.46 | 35.30 |
| **Sludge disposal (Thousand tonnes)** | | | | | |
| **Total** | 3.95 | 3.07 | 5.12 | 7.46 | 9.52 |
| **Agricultural use** | 1.55 | 0.47 | 0.48 | 0.63 | 0.76 |
| **Compost and other applications** | 0.15 | 0.78 | 0.82 | 1.97 | 2.15 |
| **Landfill** | 0.78 | 0.75 | 0.71 | 0.43 | 0.57 |
| **Incineration** | 0.09 | 0.04 | 0.01 | 0.00 | 0.06 |
| **Other** | 1.39 | 1.02 | 3.1 | 4.43 | 5.98 |
| **Produced minus disposed sludge (Thousand tonnes)** | | | | | |
| **Gap** | 15.28 | 17.58 | 16.59 | 20.00 | 25.78 |

*11. Table Sewage sludge production and disposal in Croatia, tonnes*

| | 2018 | 2019 | 2020 | 2021 | 2022 |
|---|---|---|---|---|---|
| **Sludge production (Thousand tonnes)** | | | | | |
| **Total** | 19.23 | 20.65 | 21.71 | 27.46 | 35.30 |
| **Sludge disposal (percentage)** | | | | | |
| **Total** | 21% | 15% | 24% | 27% | 27% |
| **Agricultural use** | 8% | 2% | 2% | 2% | 2% |
| **Compost and other applications** | 1% | 4% | 4% | 7% | 6% |
| **Landfill** | 4% | 4% | 3% | 2% | 2% |
| **Incineration** | 0% | 0% | 0% | 0% | 0% |
| **Other** | 7% | 5% | 14% | 16% | 17% |
| **Produced minus disposed sludge (percentage)** | | | | | |
| **Gap** | 79% | 85% | 76% | 73% | 73% |

*12. Table Sewage sludge production and disposal in Croatia, percentage*




*5. Figure: Sewage sludge disposal in Croatia*

Whereas EUROSTAT data is not available on the disposal gap, it is assumed that in some cases at least a part of the difference can be attributed to export-import, otherwise the management of this amount is unknown. The amount of sludge landfilled is decreasing whereas the share of composting and other alternative / not defined methods ("other") increases at a relatively large pace.

### 4.1.6 Germany

Due to its size, Germany produces a large amount of sewage sludge. It can be observed that here the difference between the produced and disposed of quantities is negative as of 2020. This can be explained by the import of sewage sludge.

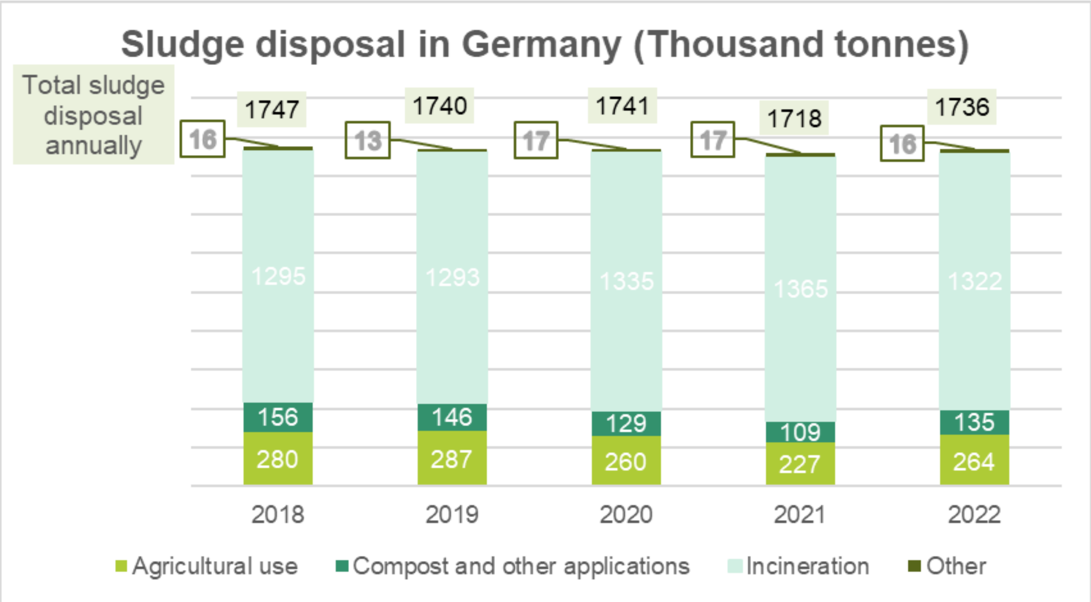
| | 2018 | 2019 | 2020 | 2021 | 2022* |
|---|---|---|---|---|---|
| **Sludge production (Thousand tonnes)** | | | | | |
| **Total** | 1,761.62 | 1,749.86 | 1,713.54 | 1,708.7 | 1,733.43 |
| **Sludge disposal (Thousand tonnes)** | | | | | |
| **Total** | 1,747.23 | 1,740.09 | 1,740.56 | 1,717.8 | 1,736.42 |
| **Agricultural use** | 280.33 | 287.48 | 259.85 | 226.75 | 263.60 |
| **Compost and other applications** | 155.82 | 146.24 | 129.04 | 108.89 | 134.99 |
| **Landfill** | 0 | 0 | 0 | 0 | 0 |
| **Incineration** | 1295 | 1293 | 1335 | 1365 | 1322 |
| **Other** | 15.9 | 13.12 | 16.68 | 17.27 | 15.74 |
| **Produced minus disposed sludge (Thousand tonnes)** | | | | | |
| **Gap** | 14.39 | 9.77 | -27.02 | -9.10 | -2.99 |

*13. Table Sewage sludge production and disposal in Germany, tonnes*

*(*the data for 2022 were not available in the EUROSTAT database when the document was prepared, so the average of previous years was taken into account for this year.)*

| | 2018 | 2019 | 2020 | 2021 | 2022* |
|---|---|---|---|---|---|
| **Sludge production (Thousand tonnes)** | | | | | |
| **Total** | 1,761.62 | 1,749.86 | 1,713.54 | 1,708.7 | 1,733.43 |
| **Sludge disposal (percentage)** | | | | | |
| **Total** | 99% | 99% | 102% | 101% | 100% |
| **Agricultural use** | 16% | 16% | 15% | 13% | 15% |
| **Compost and other applications** | 9% | 8% | 8% | 6% | 8% |
| **Landfill** | 0% | 0% | 0% | 0% | 0% |
| **Incineration** | 74% | 74% | 78% | 80% | 76% |
| **Other** | 1% | 1% | 1% | 1% | 1% |
| **Produced minus disposed sludge (percentage)** | | | | | |
| **Gap** | 1% | 1% | -2% | -1% | 0% |

*14. Table Sewage sludge production and disposal in Germany, percentage*
*(*the data for 2022 were not available in the EUROSTAT database when the document was prepared, so the average of previous years was taken into account for this year.)*




*6. Figure: Sewage sludge disposal in Germany*

It can be red from the tables and the figure that over the years there has been no significant change in the amount of sludge produced and disposed and the distribution between disposal methods. According to EUROSTAT, Germany incinerates approximately 75% of the annually disposed sewage sludge. Roughly 15% is used in agriculture, 8% is composted. The entire amount of produced and imported sewage sludge is utilized, none of it is landfilled.

### 4.1.7 Hungary

As it can be derived from the below tables and figure, the amount of produced and disposed sludge in Hungary is relatively constant with some considerable deviation in 2020. Based on EUROSTAT data, the difference between the production and disposal was negative in

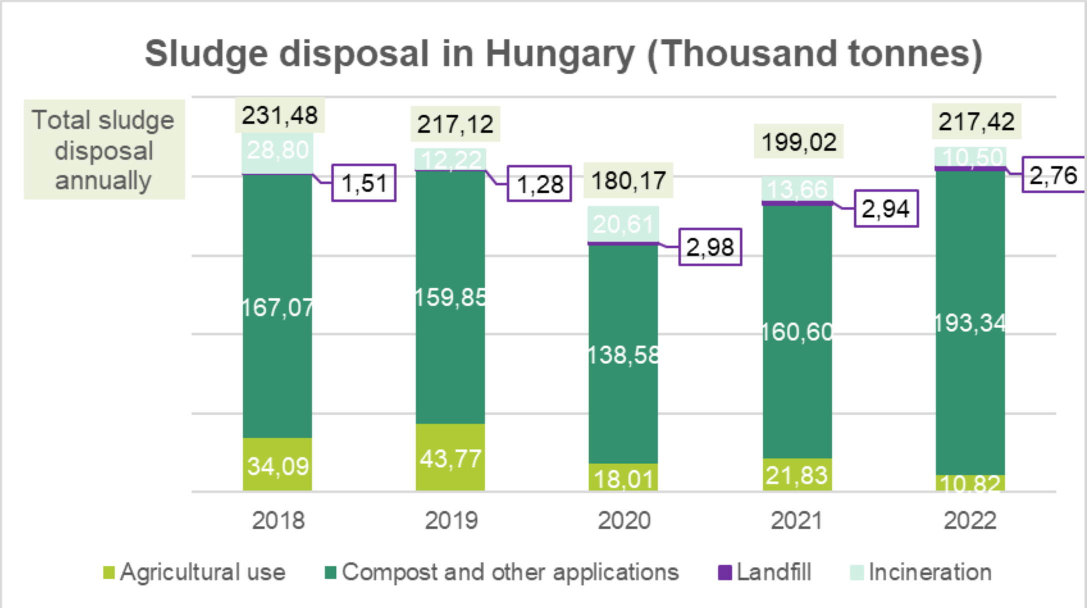
2020, which can be mostly explained by imports from neighbouring countries. In the other years, the "Gap" is positive, the management of this quantity is unknown.

| | 2018 | 2019 | 2020 | 2021 | 2022 |
|---|---|---|---|---|---|
| **Sludge production (Thousand tonnes)** | | | | | |
| **Total** | 233.66 | 227.89 | 167.03 | 226.21 | 248.08 |
| **Sludge disposal (Thousand tonnes)** | | | | | |
| **Total** | 231.48 | 217.12 | 180.17 | 199.02 | 217.42 |
| **Agricultural use** | 34.09 | 43.77 | 18.01 | 21.83 | 10.82 |
| **Compost and other applications** | 167.07 | 159.85 | 138.58 | 160.60 | 193.34 |
| **Landfill** | 1.51 | 1.28 | 2.98 | 2.94 | 2.76 |
| **Incineration** | 28.80 | 12.22 | 20.61 | 13.66 | 10.50 |
| **Other** | 0 | 0 | 0 | 0 | 0 |
| **Produced minus disposed sludge (Thousand tonnes)** | | | | | |
| **Gap** | 2.18 | 10.77 | -13.14 | 27.19 | 30.66 |

*15. Table Sewage sludge production and disposal in Hungary, tonnes*

| | 2018 | 2019 | 2020 | 2021 | 2022 |
|---|---|---|---|---|---|
| **Sludge production (Thousand tonnes)** | | | | | |
| **Total** | 233.66 | 227.89 | 167.03 | 226.21 | 248.08 |
| **Sludge disposal (percentage)** | | | | | |
| **Total** | 99% | 95% | 108% | 88% | 88% |
| **Agricultural use** | 15% | 19% | 11% | 10% | 4% |
| **Compost and other applications** | 72% | 70% | 83% | 71% | 78% |
| **Landfill** | 1% | 1% | 2% | 1% | 1% |
| **Incineration** | 12% | 5% | 12% | 6% | 4% |
| **Other** | 0% | 0% | 0% | 0% | 0% |
| **Produced minus disposed sludge (percentage)** | | | | | |
| **Gap** | 1% | 5% | -8% | 12% | 12% |

*16. Table Sewage sludge production and disposal in Hungary, percentage*




*7. Figure: Sewage sludge disposal in Hungary*

The previous diagram shows that Hungary composts the largest part of sewage sludge (72-89%). The amount utilized by incineration was roughly halved during the years under review, it has changed from 12% to 5%. The amount of sludge to be landfilled is 1% of the total amount disposed of.

### 4.1.8 Moldova

No sufficient data were found regarding Moldova.

### 4.1.9 Montenegro

No sufficient data were found regarding Montenegro

### 4.1.10 Romania

In Romania, the amount of produced sludge can differ considerably (for example between 2021 and 2022 there was a decrease of 20%), however there is no clear trend in the changes. 100% of the sewage sludge produced is disposed of, according to the EUROSTAT database, there is no disposal "Gap".

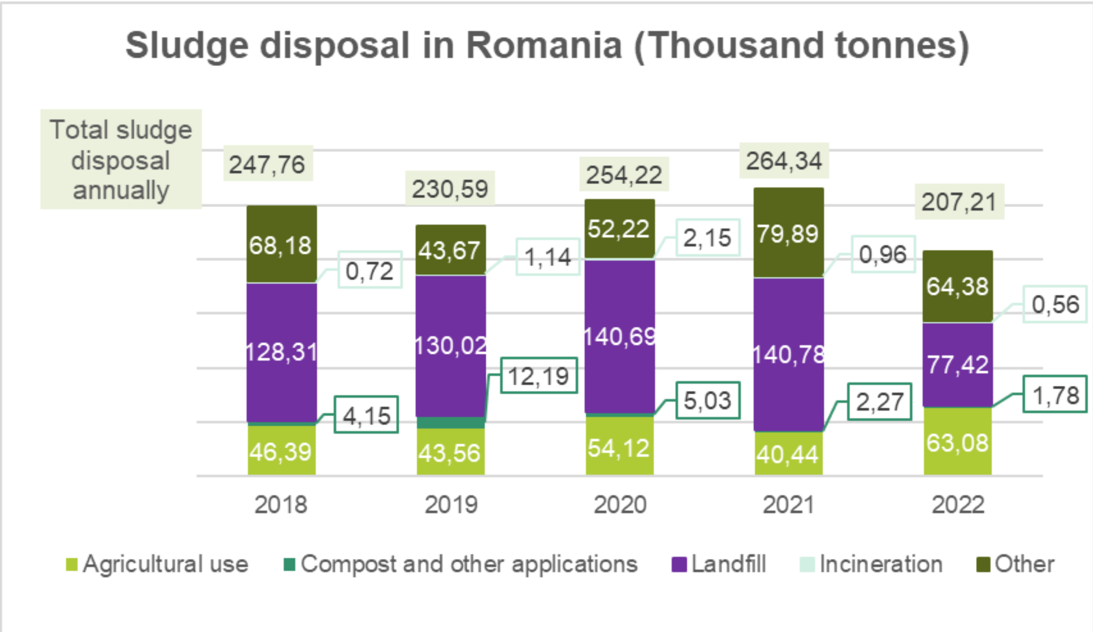
| | 2018 | 2019 | 2020 | 2021 | 2022 |
|---|---|---|---|---|---|
| **Sludge production (Thousand tonnes)** | | | | | |
| **Total** | 247.76 | 230.59 | 254.22 | 264.34 | 207.21 |
| **Sludge disposal (Thousand tonnes)** | | | | | |
| **Total** | 247.76 | 230.59 | 254.22 | 264.34 | 207.21 |
| **Agricultural use** | 46.39 | 43.56 | 54.12 | 40.44 | 63.08 |
| **Compost and other applications** | 4.15 | 12.19 | 5.03 | 2.27 | 1.78 |
| **Landfill** | 128.31 | 130.02 | 140.69 | 140.78 | 77.42 |
| **Incineration** | 0.72 | 1.14 | 2.15 | 0.96 | 0.56 |
| **Other** | 68.18 | 43.67 | 52.22 | 79.89 | 64.38 |
| **Produced minus disposed sludge (Thousand tonnes)** | | | | | |

| | 2018 | 2019 | 2020 | 2021 | 2022 |
|---|---|---|---|---|---|
| Sludge production (Thousand tonnes) | | | | | |
| Gap | 0 | 0 | 0 | 0 | 0 |

*17. Table Sewage sludge production and disposal in Romania, tonnes*

| | 2018 | 2019 | 2020 | 2021 | 2022 |
|---|---|---|---|---|---|
| Sludge production (Thousand tonnes) | | | | | |
| Total | 247.76 | 230.59 | 254.22 | 264.34 | 207.21 |
| Sludge disposal (percentage) | | | | | |
| Total | 100% | 100% | 100% | 100% | 100% |
| Agricultural use | 19% | 19% | 21% | 15% | 30% |
| Compost and other applications | 2% | 5% | 2% | 1% | 1% |
| Landfill | 52% | 56% | 55% | 53% | 37% |
| Incineration | 0% | 0% | 1% | 0% | 0% |
| Other | 28% | 19% | 21% | 30% | 31% |
| Produced minus disposed sludge (percentage) | | | | | |
| Gap | 0% | 0% | 0% | 0% | 0% |

*18. Table Sewage sludge production and disposal in Romania, percentage*




*8. Figure: Sewage sludge disposal in Romania*

Compared to 2018, the amount of sewage sludge landfilled decreased (from 52% to 37%), nevertheless, most of the sewage sludge still ends up in landfills. The amount of agricultural use of the sludge increased from 19% to 30% that is considered the main semi-resource efficient disposal method within the country. The relatively high share of "other" disposal methods (20-30%) indicates that in Romania alternative solutions with unknown environmental consequences may prevail.

### 4.1.11 Serbia

Limited data on Serbia is available in the EUROSTAT database. Based on the data shown in the tables, the production of sewage sludge in Serbia varies from year to year. A significant decrease can be seen in 2022. Serbia disposes sewage sludge solely in landfills. According to the available data, in the years of 2019 and 2020 there have been considerable disposal gaps (10 - 26%) in the country.

| | 2018 | 2019 | 2020 | 2021 | 2022 |
|---|---|---|---|---|---|
| **Sludge production (Thousand tonnes)** | | | | | |
| **Total** | 15.85 | 15.63 | 17.58 | 22.07 | 14.00 |
| **Sludge disposal (Thousand tonnes)** | | | | | |
| **Total** | 15.82 | 14.10 | 13.04 | 22.07 | 14.00 |
| **Agricultural use** | 0 | 0 | 0 | 0 | 0 |
| **Compost and other applications** | 0 | 0 | 0 | 0 | 0 |
| **Landfill** | 15.82 | 11.50 | 12.30 | 22.07 | 14.00 |
| **Incineration** | 0 | 0 | 0 | 0 | 0 |
| **Other** | 0 | 0 | 0 | 0 | 0 |
| **Produced minus disposed sludge (Thousand tonnes)** | | | | | |
| **Gap** | 0.03 | 1.53 | 4.54 | 0.00 | 0.00 |

*19. Table Sewage sludge production and disposal in Serbia, tonnes*

| | 2018 | 2019 | 2020 | 2021 | 2022 |
|---|---|---|---|---|---|
| **Sludge production (Thousand tonnes)** | | | | | |
| **Total** | 15.85 | 15.63 | 17.58 | 22.07 | 14.00 |
| **Sludge disposal (percentage)** | | | | | |
| **Total** | 100% | 90% | 74% | 100% | 100% |
| **Agricultural use** | 0% | 0% | 0% | 0% | 0% |
| **Compost and other applications** | 0% | 0% | 0% | 0% | 0% |
| **Landfill** | 100% | 74% | 70% | 100% | 100% |
| **Incineration** | 0% | 0% | 0% | 0% | 0% |
| **Other** | 0% | 0% | 0% | 0% | 0% |
| **Produced minus disposed sludge (percentage)** | | | | | |
| **Gap** | 0% | 10% | 26% | 0% | 0% |

*20. Table Sewage sludge production and disposal in Serbia, percentage*

### 4.1.12 Slovakia

Based on the data, Slovakia treats all generated sewage sludge, there is no “gap” between the produced and the disposed amount that is more or less constant over the years.

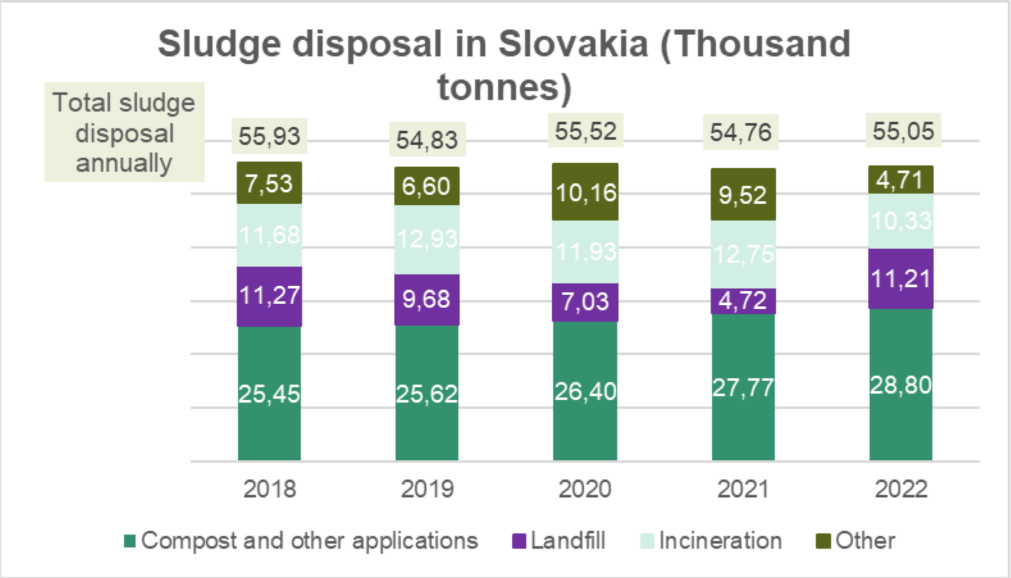
| | 2018 | 2019 | 2020 | 2021 | 2022 |
|---|---|---|---|---|---|
| **Sludge production (Thousand tonnes)** | | | | | |
| **Total** | 55.93 | 54.83 | 55.52 | 54.76 | 55.05 |
| **Sludge disposal (Thousand tonnes)** | | | | | |
| **Total** | 55.93 | 54.83 | 55.52 | 54.76 | 55.05 |
| **Agricultural use** | 0 | 0 | 0 | 0 | 0 |

| | 2018 | 2019 | 2020 | 2021 | 2022 |
|---|---|---|---|---|---|
| Sludge production (Thousand tonnes) | | | | | |
| Compost and other applications | 25.45 | 25.62 | 26.40 | 27.77 | 28.80 |
| Landfill | 11.27 | 9.68 | 7.03 | 4.72 | 11.21 |
| Incineration | 11.68 | 12.93 | 11.93 | 12.75 | 10.33 |
| Other | 7.53 | 6.60 | 10.16 | 9.52 | 4.71 |
| Produced minus disposed sludge (Thousand tonnes) | | | | | |
| Gap | 0 | 0 | 0 | 0 | 0 |

*21. Table: Sewage sludge production and disposal in Slovakia, tonnes*

| | 2018 | 2019 | 2020 | 2021 | 2022 |
|---|---|---|---|---|---|
| Sludge production (Thousand tonnes) | | | | | |
| Total | 55.93 | 54.83 | 55.52 | 54.76 | 55.05 |
| Sludge disposal (percentage) | | | | | |
| Total | 100% | 100% | 100% | 100% | 100% |
| Agricultural use | 0% | 0% | 0% | 0% | 0% |
| Compost and other applications | 46% | 47% | 48% | 51% | 52% |
| Landfill | 20% | 18% | 13% | 9% | 20% |
| Incineration | 21% | 24% | 21% | 23% | 19% |
| Other | 13% | 12% | 18% | 17% | 9% |
| Produced minus disposed sludge (percentage) | | | | | |
| Gap | 0% | 0% | 0% | 0% | 0% |

*22. Table: Sewage sludge production and disposal in Slovakia, percentage*




*9. Figure: Sewage sludge disposal in Slovakia*

The data and the diagram below show that an average of 55 thousand tonnes of sewage sludge is generated annually. Most of it (2018: 46%, 2022: 52%) is composted, 20% is landfilled, and roughly 20% is incinerated; no trend are visible in the various disposal methods.

### 4.1.13 Slovenia

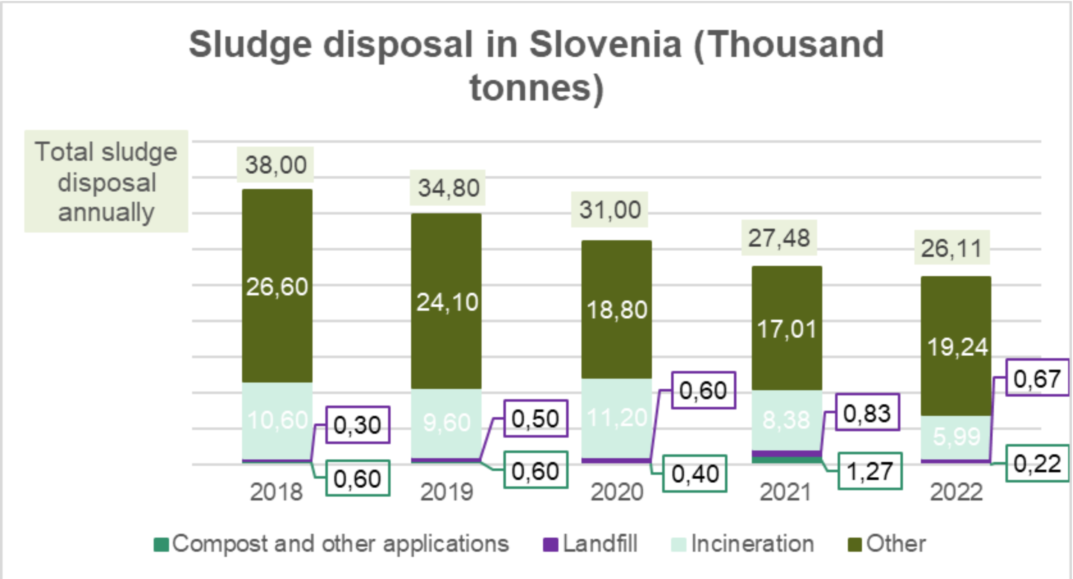
According to the EUROSTAT data on Slovenia, the amount of sewage sludge is decreasing every year (this is visible in the diagram below). Sludge is disposed of in 100%, but there is no adequate information on the method of disposal.

| | 2018 | 2019 | 2020 | 2021 | 2022 |
|---|---|---|---|---|---|
| **Sludge production (Thousand tonnes)** | | | | | |
| **Total** | 38.1 | 34.8 | 31. | 27.48 | 26.11 |
| **Sludge disposal (Thousand tonnes)** | | | | | |
| **Total** | 38.00 | 34.80 | 31.00 | 27.48 | 26.11 |
| **Agricultural use** | 0 | 0 | 0 | 0 | 0 |
| **Compost and other applications** | 0.60 | 0.60 | 0.40 | 1.27 | 0.22 |
| **Landfill** | 0.30 | 0.50 | 0.60 | 0.83 | 0.67 |
| **Incineration** | 10.60 | 9.60 | 11.20 | 8.38 | 5.99 |
| **Other** | 26.60 | 24.10 | 18.80 | 17.01 | 19.24 |
| **Produced minus disposed sludge (Thousand tonnes)** | | | | | |
| **Gap** | 0 | 0 | 0 | 0 | 0 |

*23. Table: Sewage sludge production and disposal in Slovenia, tonnes*

| | 2018 | 2019 | 2020 | 2021 | 2022 |
|---|---|---|---|---|---|
| **Sludge production (Thousand tonnes)** | | | | | |
| **Total** | 38.1 | 34.8 | 31. | 27.48 | 26.11 |
| **Sludge disposal (percentage)** | | | | | |
| **Total** | 100% | 100% | 100% | 100% | 100% |
| **Agricultural use** | 0% | 0% | 0% | 0% | 0% |
| **Compost and other applications** | 2% | 2% | 1% | 5% | 1% |
| **Landfill** | 1% | 1% | 2% | 3% | 3% |
| **Incineration** | 28% | 28% | 36% | 30% | 23% |
| **Other** | 70% | 69% | 61% | 62% | 74% |
| **Produced minus disposed sludge (percentage)** | | | | | |
| **Gap** | 0% | 0% | 0% | 0% | 0% |

*24. Table: Sewage sludge production and disposal in Slovenia, percentage*




*10. Figure: Sewage sludge disposal in Slovenia*

It can be read from the tables and the figure above that incineration is a primer disposal method (23% of the sludge was utilised in the energy industry) and there are small amounts composted (1%) or landfilled (3%). In the case of Slovenia there are considerable uncertainties in sludge management, as “other” disposal methods dominate the country’s sludge management on which data is not available. It is, however, revealed that Slovenia exports considerable amounts of sludge of sludge and there are important developments targeting the energetic utilisation and the post/processing of ashes from sludge.

#### 4.1.14 Ukraine

No sufficient data were found regarding Ukraine.

### 4.2 Sludge management in the Danube Region – a comparative summary

The summary table below shows the amount of all sewage sludge produced and disposed of by country in the examined years. Due to its size and highly developed environmental industries, Germany dominates and, thus, distortions the data considerably.

The collection and review of data from the countries in the Danube Region revealed that there is a big difference between in the Danube Region in terms of the quantity of sewage sludge and also in the technologies used for recovery. Several – mostly south-eastern – countries still work on completing their wastewater collection and treatment systems and as they do, sludge production is still low, however expected to increase. In many cases the sludge cannot be treated or disposed of yet properly because of technical difficulties.

The first obvious solution to sludge management is landfilling or storing as seen in Serbia, Bosnia and Herzegovina and the Ukraine. Then a shift can be seen in disposal to agricultural use being the most common technique for example in the Czech Republic. Germany and Austria incinerate most of the sludge produced.

| | Population (million) | 2018 | | | 2019 | | | 2020 | | | 2021 | | | 2022 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Prod | Disp | Gap | Prod | Disp | Gap | Prod | Disp | Gap | Prod | Disp | Gap | Prod | Disp | Gap |
| **Austria** | 9 | 234 | 234 | 0 | 234 | 234 | 0 | 228 | 228 | 0 | 194 | 194 | 0 | 196 | 196 | 0 |
| **BiH** | 3 | 10 | 10 | 0 | 10 | 10 | 0 | 10 | 10 | 0 | 10 | 10 | 0 | 10 | 10 | 0 |
| **Bulgaria** | 6 | 53 | 42 | 11 | 44 | 33 | 11 | 34 | 28 | 5 | 39 | 27 | 12 | 43 | 33 | 10 |
| **Czech Rep.** | 11 | 228 | 228 | 0 | 221 | 221 | 0 | 219 | 219 | 0 | 235 | 235 | 0 | 244 | 244 | 0 |
| **Croatia** | 4 | 19 | 4 | 15 | 21 | 3 | 18 | 22 | 5 | 17 | 27 | 7 | 20 | 35 | 10 | 26 |
| **Germany** | 84 | 1762 | 1747 | 14 | 1750 | 1740 | 10 | 1714 | 1741 | -27 | 1709 | 1718 | -9 | 1733 | 1736 | -3 |
| **Hungary** | 10 | 234 | 231 | 2 | 228 | 217 | 11 | 167 | 180 | -13 | 226 | 199 | 27 | 248 | 217 | 31 |
| **Moldova** | 2,5 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| **Montenegro** | 0.6 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| **Romania** | 19 | 248 | 248 | 0 | 231 | 231 | 0 | 254 | 254 | 0 | 264 | 264 | 0 | 207 | 207 | 0 |
| **Serbia** | 7 | 16 | 16 | 0 | 16 | 14 | 2 | 18 | 13 | 5 | 22 | 22 | 0 | 14 | 14 | 0 |
| **Slovenia** | 2 | 38 | 38 | 0 | 35 | 35 | 0 | 31 | 31 | 0 | 27 | 27 | 0 | 26 | 26 | 0 |
| **Slovakia** | 5 | 56 | 56 | 0 | 55 | 55 | 0 | 56 | 56 | 0 | 55 | 55 | 0 | 55 | 55 | 0 |
| **Ukraine** | 38 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| **total** | **198** | **2897** | **2855** | **43** | **2843** | **2792** | **51** | **2751** | **2765** | **-14** | **2808** | **2759** | **50** | **2811** | **2748** | **63** |

*25. Table: Summary of the countries' sewage sludge production and disposal (thousand tonnes)*
*(dark grey cells: estimations from previous years due to data gaps for the actual year)*

## Sludge production

| | Population (million people) | Sludge production in kg/capita/year | | | | |
|---|---|---|---|---|---|---|
| | | 2018 | 2019 | 2020 | 2021 | 2022 |
| **Austria** | 9.0 | 25.9 | 25.8 | 25.2 | 21.4 | 21.7 |
| **Bosnia and Herzegovina** | 3.2 | 2.9 | 2.9 | 2.9 | 2.9 | 2.9 |
| **Bulgaria** | 6.5 | 8.2 | 6.9 | 5.2 | 6.1 | 6.6 |
| **Czech Rep.** | 10.7 | 21.4 | 20.7 | 20.5 | 22.0 | 22.8 |
| **Croatia** | 3.9 | 5.0 | 5.4 | 5.6 | 7.1 | 9.2 |
| **Germany** | 83.8 | 21.0 | 20.9 | 20.4 | 20.4 | 20.7 |
| **Hungary** | 9.6 | 24.3 | 23.7 | 17.4 | 23.6 | 25.8 |
| **Moldova** | 2,5 | - | - | - | - | - |
| **Montenegro** | 0.6 | - | - | - | - | - |
| **Romania** | 19.1 | 13.0 | 12.1 | 13.3 | 13.9 | 10.9 |
| **Serbia** | 6.7 | 2.4 | 2.3 | 2.6 | 3.3 | 2.1 |
| **Slovenia** | 2.1 | 18.0 | 16.5 | 14.7 | 13.0 | 12.4 |
| **Slovakia** | 5.4 | 10.3 | 10.1 | 10.2 | 10.1 | 10.1 |
| **Ukraine** | 38.0 | - | - | - | - | - |

*26. Table: Sludge production per capita (kg)*

The above figure compares quantities of sludge per 1000 persons. The table presents the per capita sludge production in the examined countries from 2018 to 2022. Several observations can be made from the data:

- Country variations: There are significant differences in sludge production between countries. While Austria and Germany exhibit relatively high per capita sludge production, countries like Serbia and Montenegro have significantly lower rates.
- Temporal changes: Sludge production has fluctuated over time in some countries. For instance, Hungary experienced a notable decrease in 2020, whereas Croatia saw a significant increase between 2021 and 2022.
- Data gaps: The table contains missing data for several countries (Moldova, Montenegro, Ukraine), hindering comprehensive analysis.

Potential explanations for these variations:

- Level of sewage / wastewater collection and treatment: the most obvious reason behind the variations on volume is the development of the wastewater treatment facilities. As in lower income countries large investments are still expected to enter the sector, mid/ and higher income countries have already well established their sewage and waste water systems.
- Economic development: Developed countries generally have higher levels of industrial and agricultural activity, leading to larger volumes of wastewater and consequently, more sludge.
- Wastewater treatment technologies: The employed wastewater treatment technologies can influence sludge production.

- **Population density**: More densely populated areas typically have higher wastewater loads, resulting in increased sludge generation.
- **Food industry**: The food industry produces substantial organic waste, which can contribute to higher sludge volumes.
- **Data collection methods: Differences in data collection methodologies across countries can partially account for the observed variations.**

In many countries quantities are expected to increase considerably to approximately 20-25 tonnes/1000 persons similarly to Austria. This applies primarily to the countries of the south-eastern part of the region, with a medium-moderate population; thus overall amount of sludge produced in the Danube basin is also expected to increase considerably.

### Sludge recovery

The summary data on sludge management methods is presented in the below table.

| 2022 | Total Sludge disposal (%) | Agricultural use (%) | Compost and other applications (%) | Landfill (%) | Incineration (%) | Other (%) |
|---|---|---|---|---|---|---|
| **Bulgaria** | 77 | 53 | 8 | 5 | 0 | 11 |
| **Czech Rep.** | 100 | 35 | 46 | 8 | 11 | 0 |
| **Germany** | 100 | 15 | 8 | 0 | 76 | 1 |
| **Croatia** | 27 | 2 | 6 | 2 | 0 | 17 |
| **Hungary** | 88 | 4 | 78 | 1 | 4 | 0 |
| **Austria** | 100 | 26 | 20 | 0 | 45 | 10 |
| **Romania** | 100 | 30 | 1 | 37 | 0 | 31 |
| **Slovenia** | 100 | 0 | 1 | 3 | 23 | 74 |
| **Slovakia** | 100 | 0 | 52 | 20 | 19 | 9 |
| **BiH** | 100 | 0 | 0 | 100 | 0 | 0 |
| **Serbia** | 100 | 0 | 0 | 100 | 0 | 0 |
| **Moldova** | - | - | - | - | - | - |
| **Ukraine** | - | - | - | - | - | - |
| **Montenegro** | - | - | - | - | - | - |

*27. Table: Percentage distribution between disposal methods, 2022*
*(dark grey cells: estimations from previous years due to data gaps for the actual year)*

The first obvious solution to sludge management is landfilling or storing as seen in Bosnia and Herzegovina, Serbia and partly in Romania and Slovakia. Agricultural disposal is still the most common method, primarily in in Bulgaria but also in Romania and and the Czech Republic. Germany and Austria incinerate most of their sludge produced. Check Republic, Hungary and Slovakia put emphasis on composting that is considered a rather favourable relatively low-cost solution both from the energy industry and nutrient recovery points of view.

### The disposal gap

The table below shows the countries with more than 1% "disposal gap", i.e. a discrepancy between the amount of produced sewage sludge and the amount of treated sewage sludge (Bulgaria, Croatia, Germany, Hungary, Serbia – until 2020). Whereas in the cases of Germany and Hungary the negative gap can be associated with export-import activities, in other cases the gap shows possible contradictions in disposal, and-or data recording and reporting.

| | 2018 (%) | 2019 (%) | 2020 (%) | 2021 (%) | 2022 (%) |
|---|---|---|---|---|---|
| **Austria** | 0 | 0 | 0 | 0 | 0 |
| **BiH** | 0 | 0 | 0 | 0 | 0 |
| **Bulgaria** | 20 | 25 | 15 | 30 | 23 |
| **Czech Rep.** | 0 | 0 | 0 | 0 | 0 |
| **Croatia** | 79 | 85 | 76 | 73 | 73 |
| **Germany** | 1 | 1 | -2 | -1 | 0 |
| **Hungary** | 1 | 5 | -8 | 12 | 12 |
| **Moldova** | - | - | - | - | - |
| **Montenegro** | - | - | - | - | - |
| **Romania** | 0 | 0 | 0 | 0 | 0 |
| **Serbia** | 0 | 10 | 26 | 0 | 0 |
| **Slovenia** | 0 | 0 | 0 | 0 | 0 |
| **Slovakia** | 0 | 0 | 0 | 0 | 0 |
| **Ukraine** | - | - | - | - | - |

*28. Table: Gap between the sludge production and sludge disposal (%)*

In conclusion, sludge treatment and disposal techniques in the Danube Region exhibit significant diversity, and in many cases, there is insufficient data to accurately assess the prevailing trends. To gain a more comprehensive understanding of sludge management in the region, further data collection and research are necessary.

### The export-import of sludge

Many countries in the region, as well as others in the EU, rely on other member states' sludge recovery capacities. Many times, the reason for this is either stricter regulation in a given country, or greater vulnerability at given locations for feasible, cost saving solutions. The receiving countries, on the other hand, can better utilise their capacities and they are better off due to the scale of economies. Sludge is usually transported after a pre-treatment of drying that is the first step of any sludge recovery. Transport modes, due to relatively large quantities are usually train, shipping and partly road freight.

The export-import of sludge falls under the EU regulations on hazardous waste: sludge itself is considered a **notified non-hazardous waste**, meaning that due to its polluting potentials close monitoring and tracking is required, however, after proper treatment it can be recovered; the regulations include standards for the handling and transporting and reporting on sludge export and import. This means that besides bilateral agreements, the close monitoring of sludge is necessary. In spite of this, there is little data available on export-import of sludge.

**Also, some hazardous materials under the regulations may be final or interim products of sludge treatment. Fly ash** typically falls into this category as the residual of sludge incineration may be exported to other countries where, phosphorous removal capacities exist. In this way transport costs can be decreased considerably by the sending countries and the receiving country's capacities are better utilised especially in regards to the expensive and large scale phosphorous recovery plants.

According to the limited data on hazardous waste shipments published by EUROSTAT[31], in 2016 a total amount of 340 thousand tonnes of sludge was exported by EU member states (this equals to the amount produced by Austria, Slovakia and Slovenia together). The three main types of recovery techniques registered concerning the exported sludge were incineration (D10 – 60%), reuse of sludge as fuel / co-incineration (R1 – 20%) and organic substance recycling/reclamation (R3 – 20%). In 2016, among the three main exporting countries Slovenia exported some 41 thousand tonnes; the largest exporter country was the Netherlands with more than 110 thousand tonnes. Among the three largest importing countries we can find Germany leading the chart with more than 192 thousand tonnes and Hungary, being the second, with almost 83 thousand tonnes.

It is known that Slovenia's export, mostly sludge form the Maribor waste water treatment plant, was shipped to Hungary[32]; Hungary withdrew from the bilateral export-import agreement in 2019 and with this the considerable amount of sludge produced in the Maribor WWTP has to be recovered elsewise, causing some problems to the Slovenian sludge management system. As a reaction, Maribor made plans to recover its sludge for the use of the building industry and built an incineration plant also for the energetic recovery of its communal wastes. This case shows vulnerability of export-import arrangements. Meanwhile the final resolution of the sewage problems in Slovenia, the dewatered sludge is now exported to Austria, where the Klagenfurt incinerator and recovery plant utilises the sludge from Slovenia through incineration and performs phosphorous removal. It is important to note that these considerable amounts of export-import are not reflected in the Eurostat databases, Slovenia indicates this amount under "other" disposal/recovery technique, whereas in the of Austria there is no indication of whatsoever concerning sludge imported from Slovenia.

[31] Eurostat (quoted: 20.11.2020): Waste shipment statistics based on the European list of waste codes; https://ec.europa.eu/eurostat/statistics-explained/index.php/Waste_shipment_statistics_based_on_the_European_list_of_waste_codes#Non-hazardous_notified_waste_based_on_LoW

[32] Vecer.com

# 5 Survey on sludge management

To acquire first-hand information on the present challenges of sewage sludge treatment, an online survey was organised for the representatives of the Danube Region. The survey was conducted starting the beginning of November 2024, and was closed at the 20 of November. Professionals from the EUSDR PA4 steering committee members, the national and professional representatives of the International Commission for the Protection of the Danube River (ICPDR), as well as their professional partners participated in the survey.

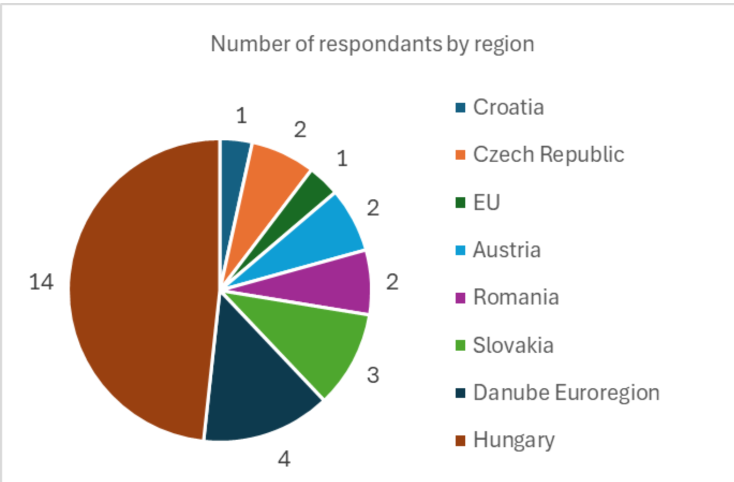
The survey was organized around 5 sections targeting different aspects of the sludge management:

1. Basic information on the participants (represented country, organisation)
2. National and community level policies, strategies and legislation
3. Applied and available technologies
4. Management issues
5. Final notes

In each sections of 1-4, there were 4-6 single and multiply choice, and/or free text questions, whereas section 5 gave room for the sharing of additional information considered relevant by the respondents. The detailed questionnaire is found in Annex 2.

## 5.1 Represented countries and organisations

There were 28 responses submitted; the national / organisational affiliation of the respondents is as follows:




*11. Figure: Represented countries/regions in the survey*

Almost half of the EUSDR countries, 6 out of the 14 countries were represented in the survey, Hungary, the host country of the water quality priority area, being overrepresented. The German regions of Baden-Württemberg and Bavaria, the most populous region participating in the EUSDR was not represented in the survey; this means that the survey is not representative for the entire region, however, it still provides for important information primarily for the central and low-stream areas of the Danube.

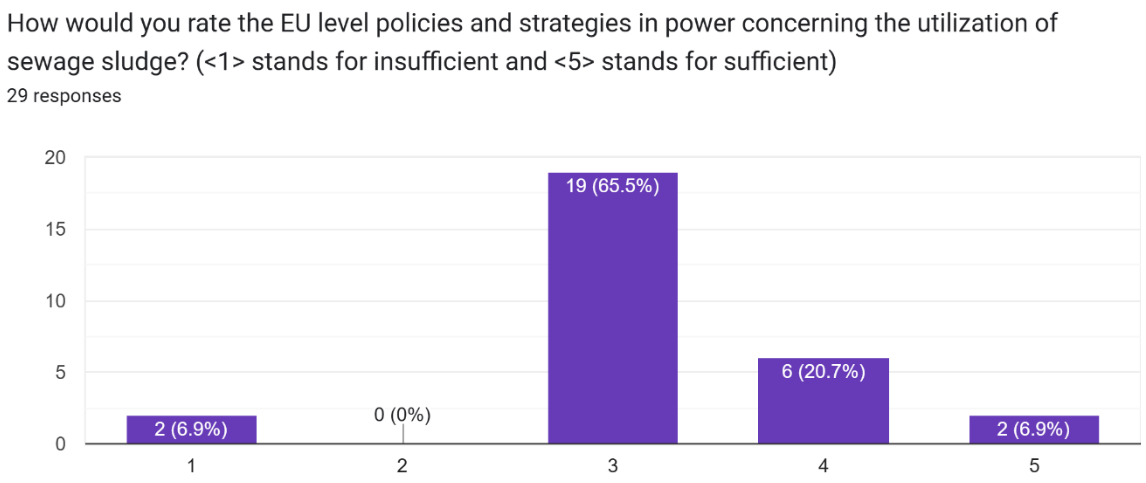
The participants in the survey are primarily from the national water administration, such as ministries, and water management directorates, research institutions and water utility companies, thus both policy level and operational level inputs could be considered.

## 5.2 Policies, strategies and legislation

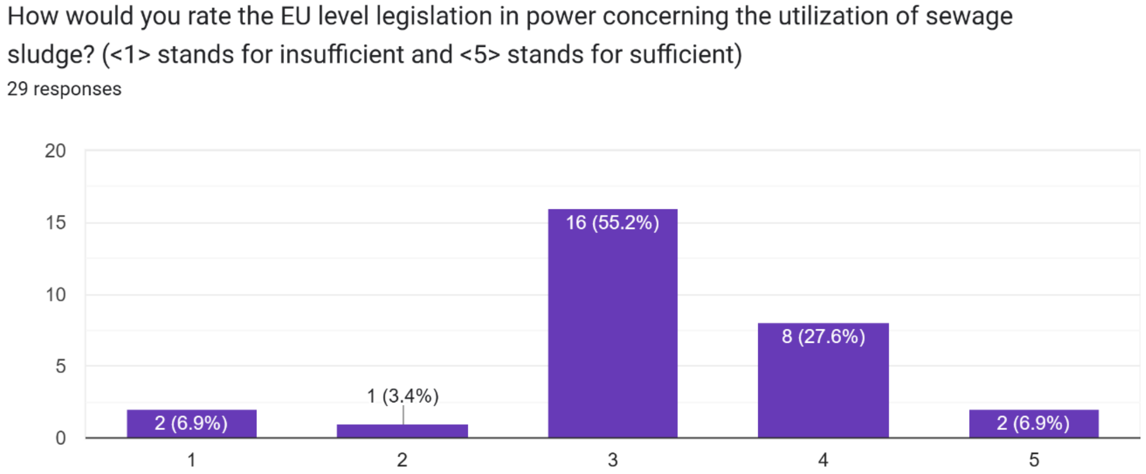
According to the results the most important policy advances on EU level were the establishment and tightening of the requirements of sewage treatment including sewage sludge management. Among the advances, monitoring received primarily attention as well. Among the most recent advances the encouragement of environmentally friendly solutions were in the forefront; the specific issues raised in line with the Wastewater Treatment and Sewage Sludge Directive, the "Farm to Fork" Strategy, The EU's new Soil Protection Thematic Strategy, and the Circular Economy Action Plan, included:

- nutrient recovery,
- energy recovery,
- the stricter regulation, sometimes banning of using sludge products on agricultural land,
- putting emphasis on the stricter regulation specific contaminants (TPH, microplastics, pharmaceuticals, etc.).

Having all these issues considered, opinions of the present EU level strategies and regulations are generally regarded only fairly accurate, however its outdatedness is strongly pointed out. The results show that the respondents consider the present strategies satisfactory, however they criticise its focus on agricultural use and not giving enough room emerging technologies/solutions and for local and/or specific conditions that may greatly influence the success of the possible sludge management solutions.

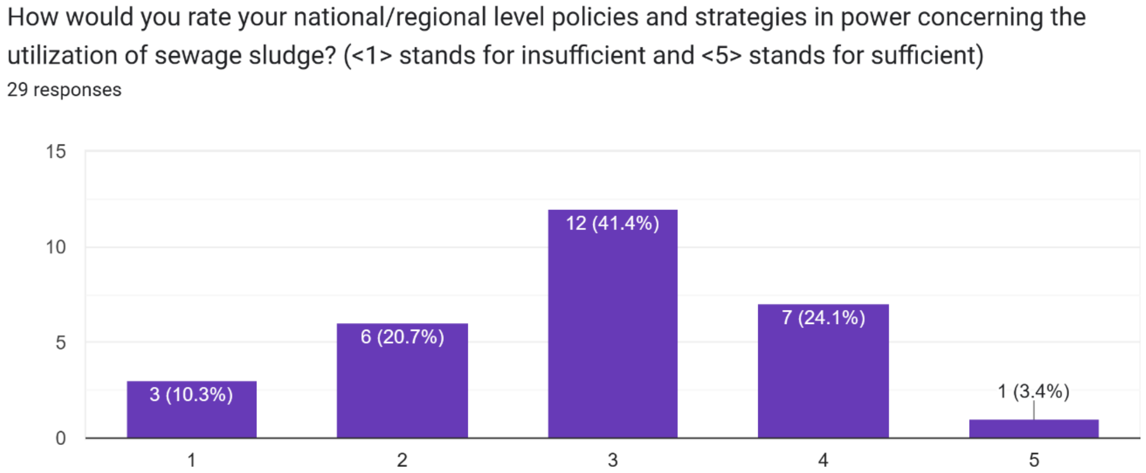



*12. Figure: The rating of EU level policies and strategies*

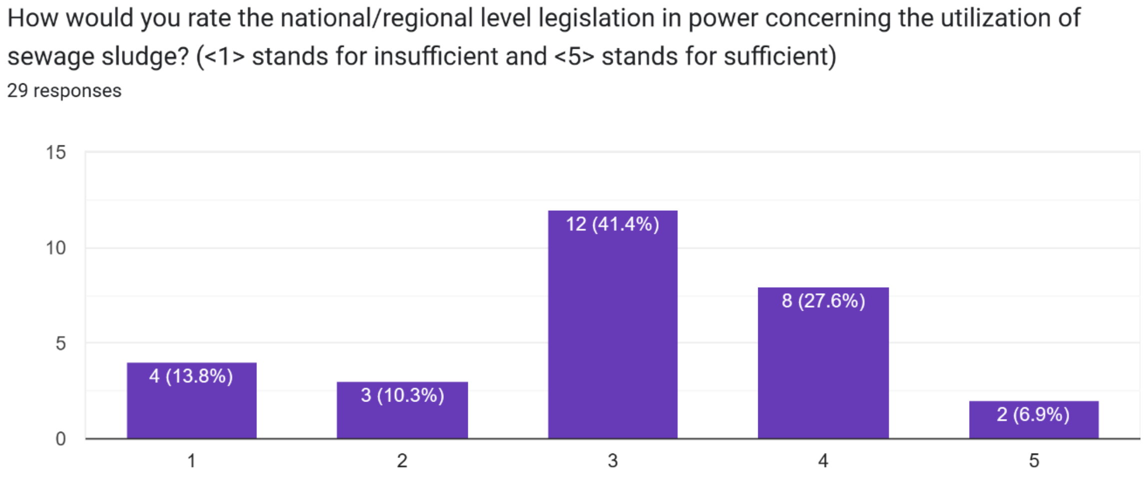



*13. Figure: The rating of EU level legislation*

National level strategies were performing very similarly in the survey. It is important to note that more than one respondents pointed to the fact that national level strategies are missing (Kosovo) weak (Hungary) or outdated (focus on agricultural use), and many times only follow the adoption of the EU legislation; however, in some cases, national legislation and strategies were considered even stricter than the community ones (Austria).



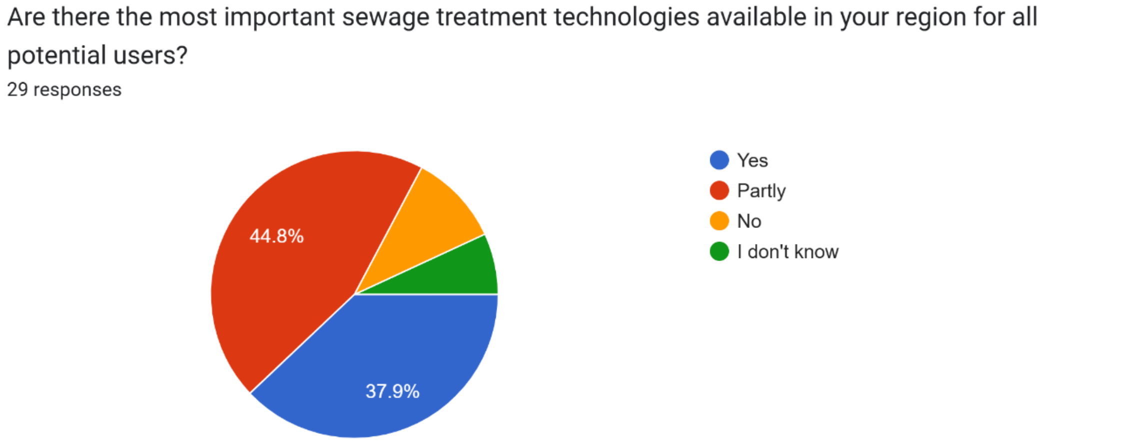

*14. Figure: The rating of national level policies and strategies*




*15. Figure: The rating of national level legislation*

## 5.3 The application of sewage sludge recovery techniques and technologies

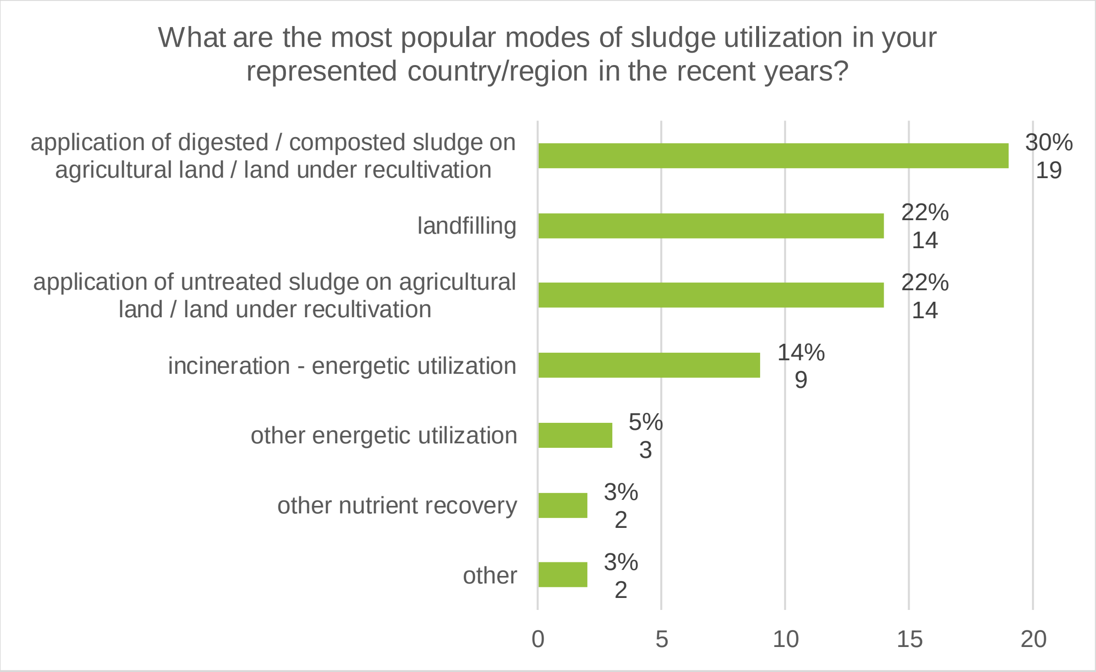
Concerning the availability and the application of the various sludge recovery techniques its can be concluded that the picture is rather diverse within the region. Firstly, it has to be pointed out that the full range of technologies are not fully available for the potential users:




*16. Figure: The availability of sludge management technologies for potential users*

This availability, however, is implicitly considered a financial availability, as respondents from the same country gave contradictory answers. In summary it can be stated that the "physical" availability is usually provided, however financial means for the procurement of the most recent technologies, or the feasibility of the application of such technologies is not always secured.

Concerning the applied technologies, the picture is somewhat contradictory when compared with the data published by the Eurostat.

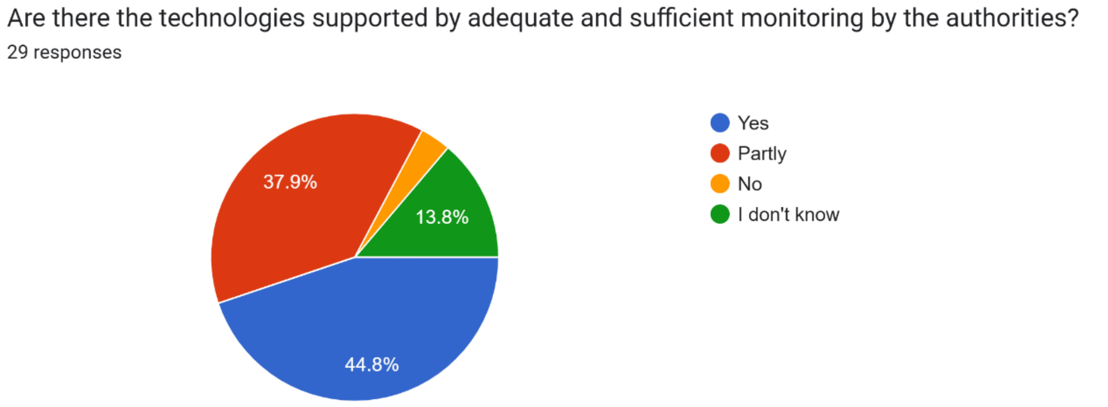



*17. Figure: Sludge utilisation modes*

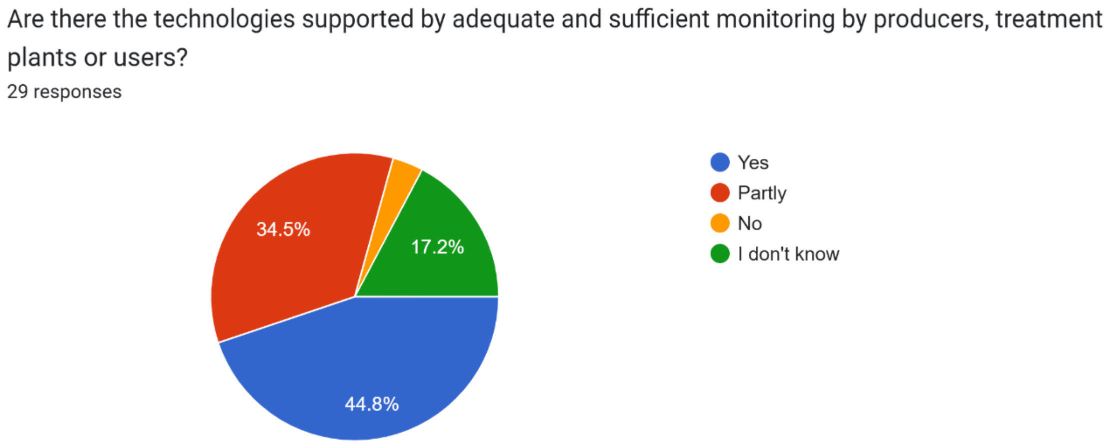
The application of compost products on agricultural land is considered the most popular mode of sludge utilisation, however this result can be primarily associated with the overrepresentation of Hungary in the survey; this method in Hungary is widely applied. The high scores of landfilling, however, clearly indicates issues with data collecting/reporting and monitoring as well as draws attention to the need to develop national strategies and invest in the sector to enhance resource efficiency. Also, the relatively high score of direct application of stabilised sludge in agriculture shows data reporting issues, and the fact that there is still considerable room to improve resource efficiency and draws attention to soil quality issues through the strong control of contaminants.

Austria and Kosovo relies greatly on incineration, however, whereas in Kosovo co-incineration prevails, in Austria the advanced and energy intensive methods of mono-incineration with nutrient recovery is the most wide/spread solution (the phenomena clearly roots in national strategies and the financial availability of technologies).

Concerning the monitoring of the processes parallel to the various technologies, it can be stated that the system still needs improvements in regards to avoiding the potential pollution of soils and waters. According to the survey, monitoring is fully sufficient in the 43% of the cases (Austria, partly Hungary, Romania and Slovakia) and partly sufficient in the 35-40% of the cases. Insufficient monitoring was reported only in one case (Kosovo).



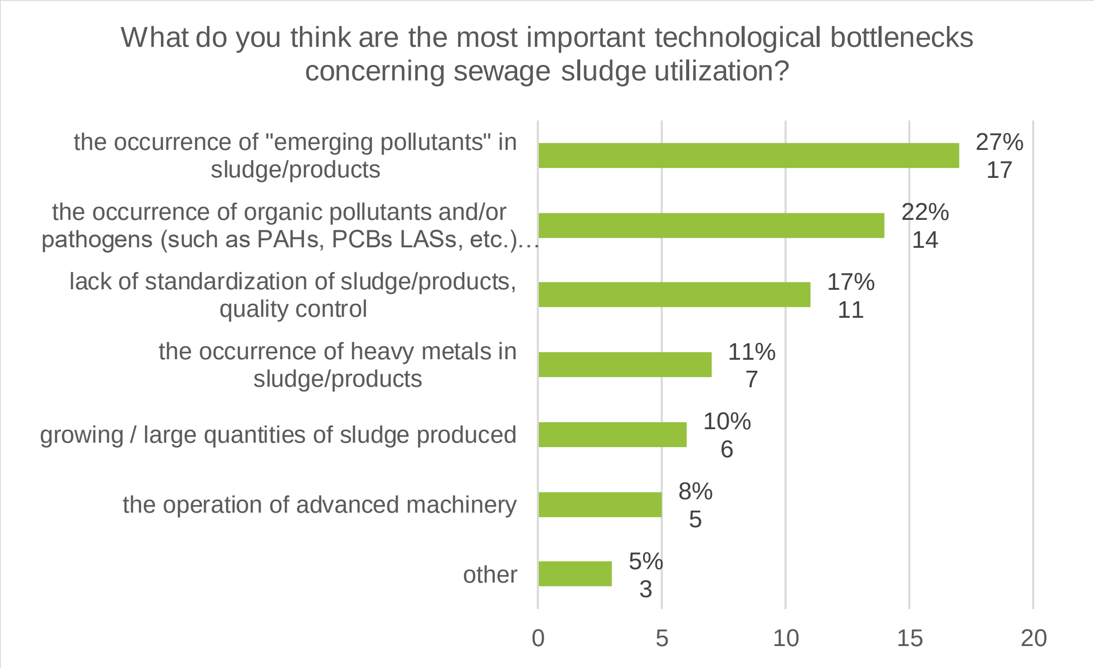

*18. Figure: The rating of monitoring by authorities*




*19. Figure: The rating of monitoring by non-governmental stakeholders*

Concerning technological bottlenecks it can be concluded that as of today, sludge recovery treatment technologies applied are relatively well prepared to manage the tasks, however there are growing concerns with the technological management of the “emerging” pollutants. Also, according to the survey technologies are well prepared for the treatment various organic pollutants; these technologies are many times pollutant-specific and usually expensive to apply. Heavy metals and sludge quantities still play important role in the efficiency of the sludge treatment technologies.

Important factors in the technological preparedness are the standards and quality control of sludge / products. These issues is receiving growing recognition especially in the light of the high concerns with the emerging and organic pollutants and the need for the revision of the strategies and regulations.



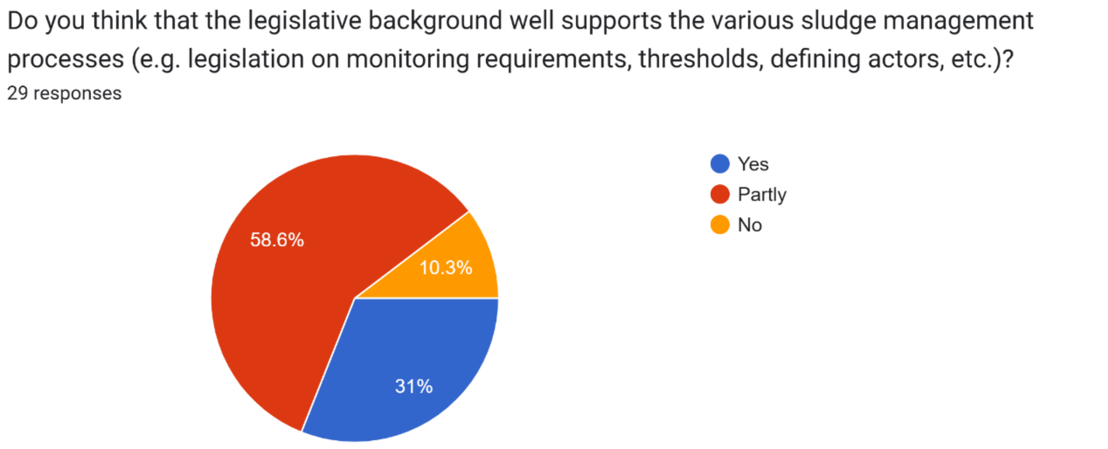

*20. Figure: Technological bottlenecks in sludge recovery*

Important elements of technological bottlenecks pointed to by the respondents are:

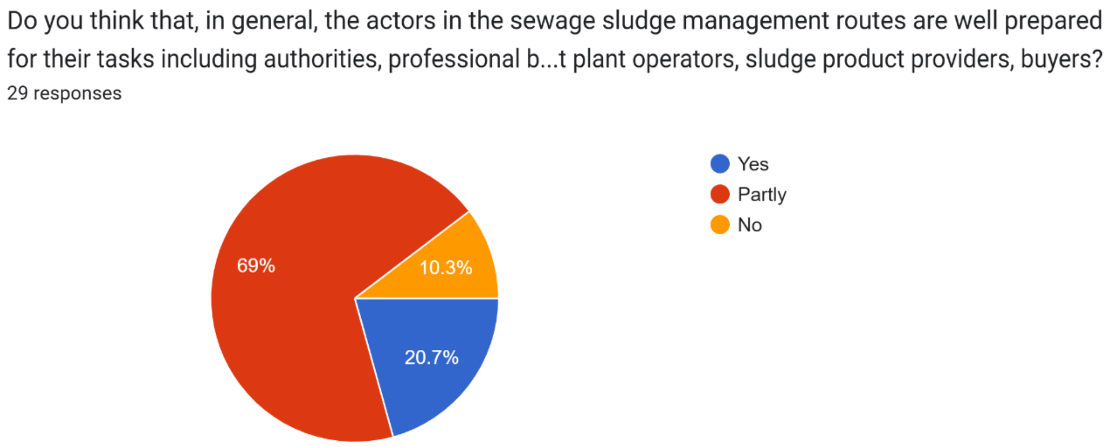
- Transport of sludge / products
- Improving phosphorous recovery techniques
- The impacts of industrial sewage on the sewage and sludge treatment processes
- Co-operation among other waste management routes, primarily green waste processing
- The question of scale; feasible technologies for small scale operations

## 5.4 Management of the sludge recovery and utilisation

The background of sludge management roots in the legislative and regulatory background as well as in the preparedness of the actors. These factors are considered rather contradictory according to the answers of the respondents: in 10% of the responses, regulations and actors were rated “not well prepared” for successful sludge management.



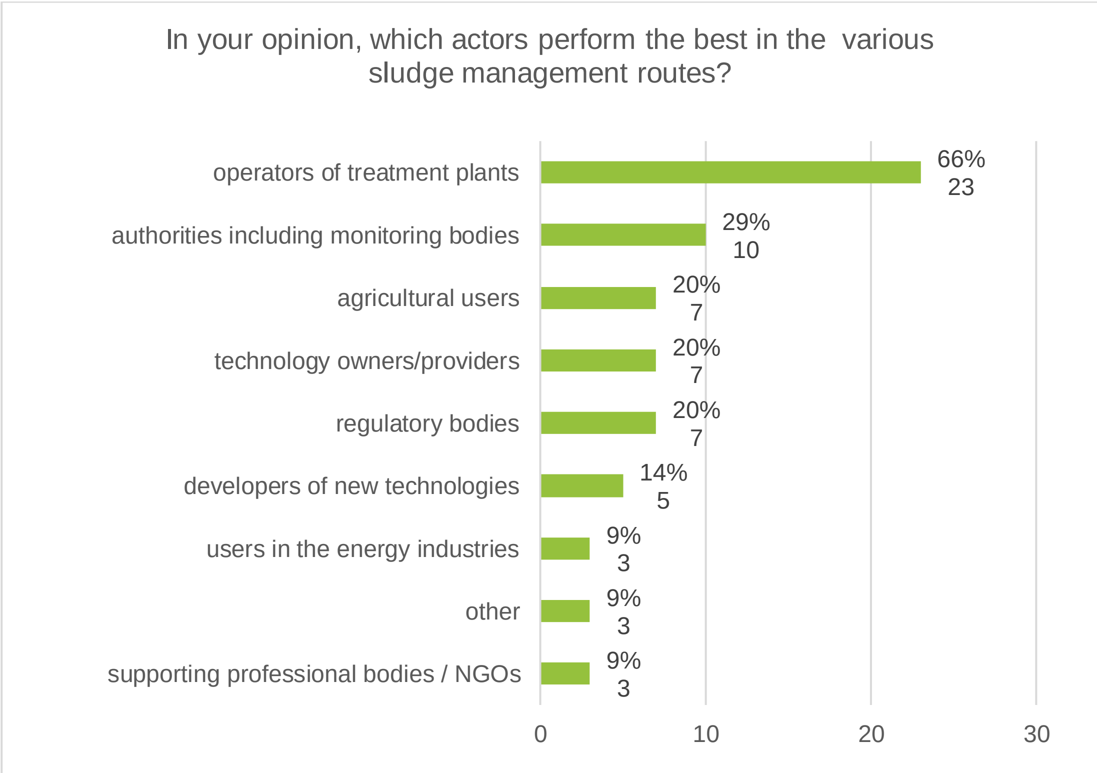

*21. Figure: The rating of the regulatory background of sludge management*




*22. Figure: The rating of the preparedness of the actors in sludge management*

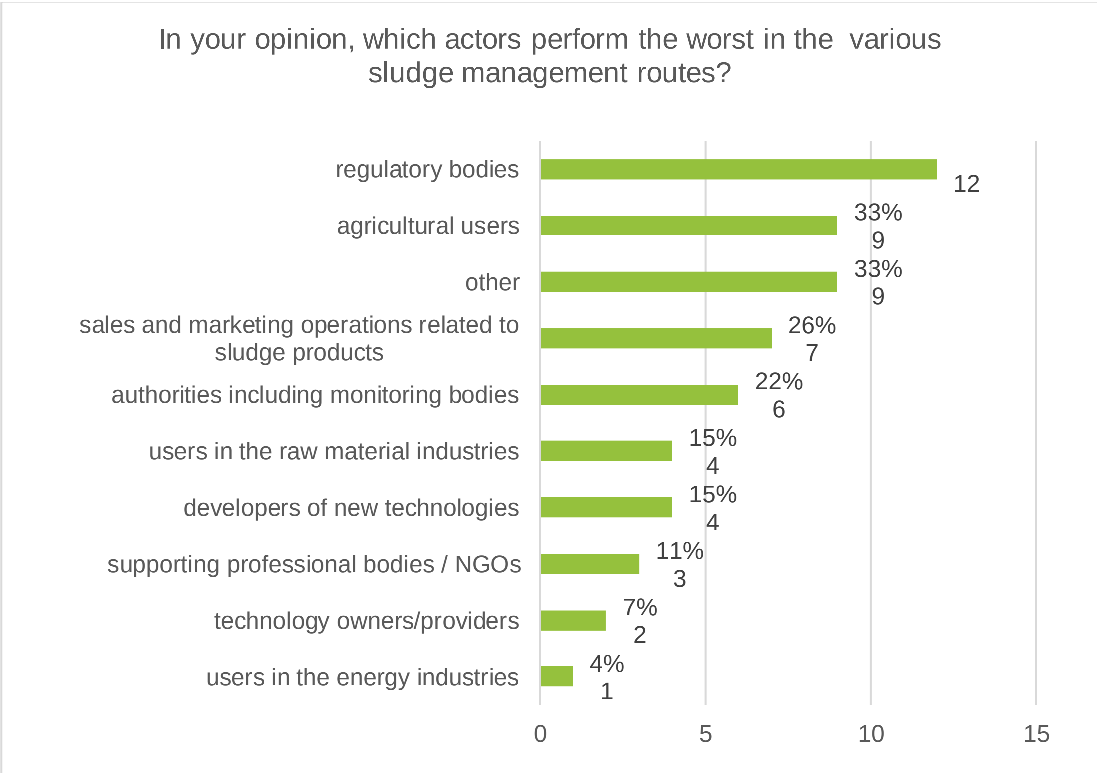
According to the results, sufficient regulations and well prepared actors are present only in the smaller part of the cases (31% and 21% respectively), and in around 60% and 70% of the cases there is still considerable room for the improvement of both the regulatory framework and the preparedness of the actors. Sufficient regulatory framework was reported mainly from Austria, the Czech Republic, Slovakia and Hungary, inadequate regulatory background was identified by Hungarian actors; this means that the picture in Hungary is at least contradictory, however the issue may be related to the distorted representativity of Hungary in the survey. In summary the regulations in most of the cases of the EUSDR countries can be considered not supportive. The picture is similar in the case of the preparedness of the actors as well.

Concerning the best performing actors, the operators of the sewage treatment plants "easily won the competition". This phenomenon is related to the fact that the operators are in charge of the actual management of sludge, are financially directly exposed to the activities and the markets and, thus, try to find the most feasible solutions for the sustainable management of sludge. In only one third of the cases were authorities considered supportive enough, and regulatory bodies even fall behind this figure being of great help in only one fifth of the cases. Agricultural users and technology providers are considered good partners by every 4th respondents only. According to the survey, other supporting organisations, such professional bodies, NGOs or country assembles can give substantial support only in the 7% of the cases, however, these potentially can be important forums of knowledge exchange.



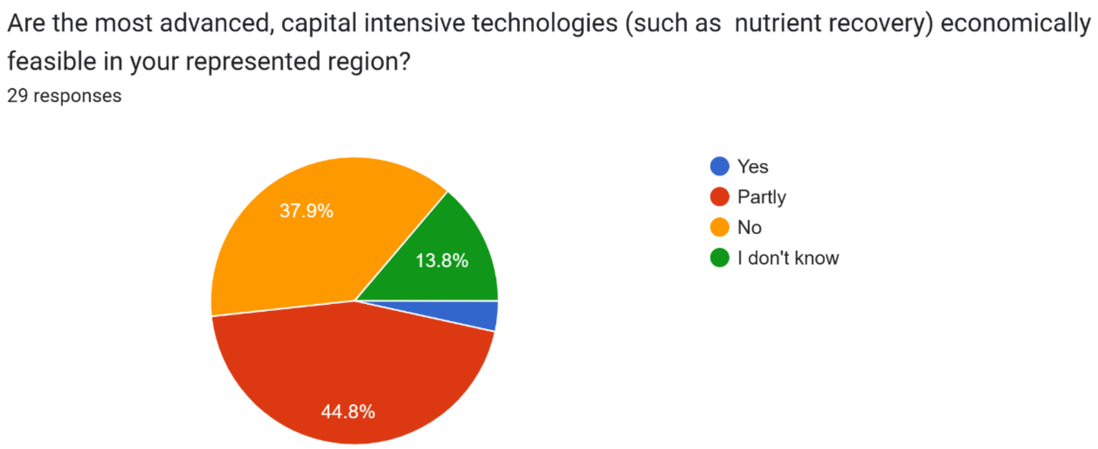

*23. Figure: The best performing actors in sludge management routes*

Concerning the worst performing actors, unfortunately the key player of regulatory bodies leads the chart followed by agricultural users. This phenomenon is rather unfavourable as they are the beginning and the end of many of the sludge management routes. Considerable bottlenecks were identified also in the work of authorities, and the sales and marketing operators.




*24. Figure: The worst performing actors in sludge management routes*

As new concerns arise (such as limits to agricultural use, resource efficiency, available land for recultivation, pollutants of growing concern), emerging technologies play important role in the future operations. The feasibility of the new technologies, however, requires an environment where markets as well as sound management are prepared. According to the results, the Danube Region as a whole is not prepared for the application of the new technologies, and the new energy and capital intensive technologies providing for greater environmental benefits are far from feasible.

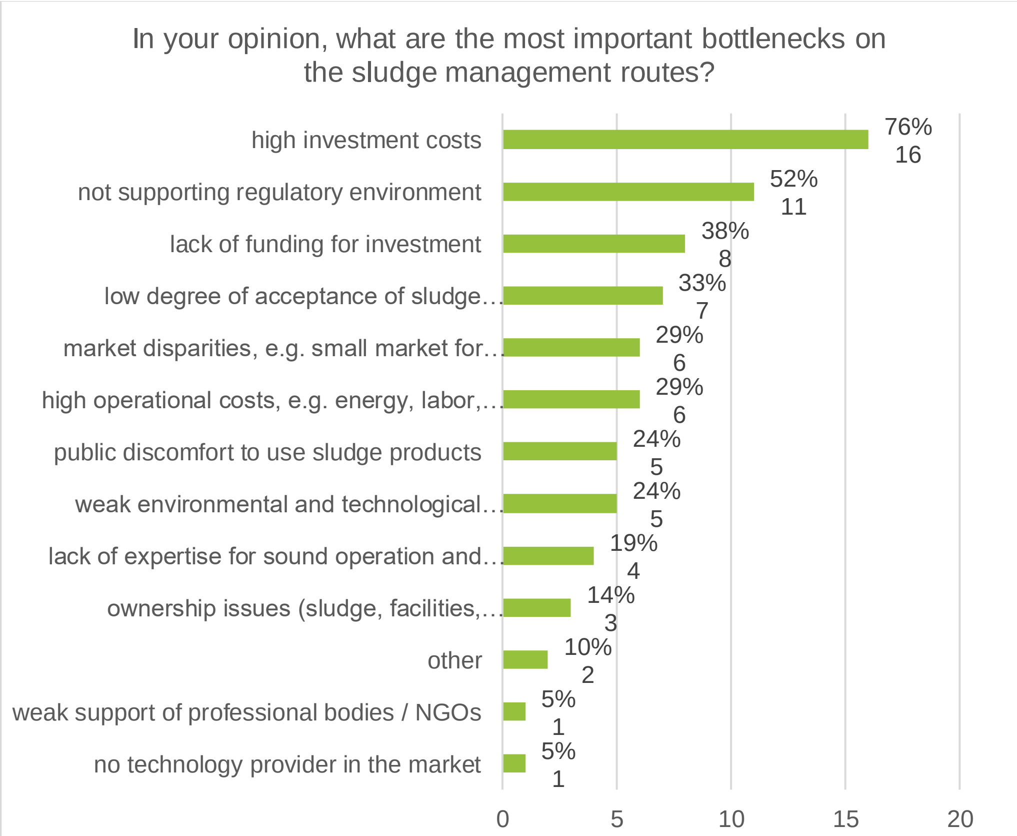



*25. Figure: The feasibility of the application of the new technologies*

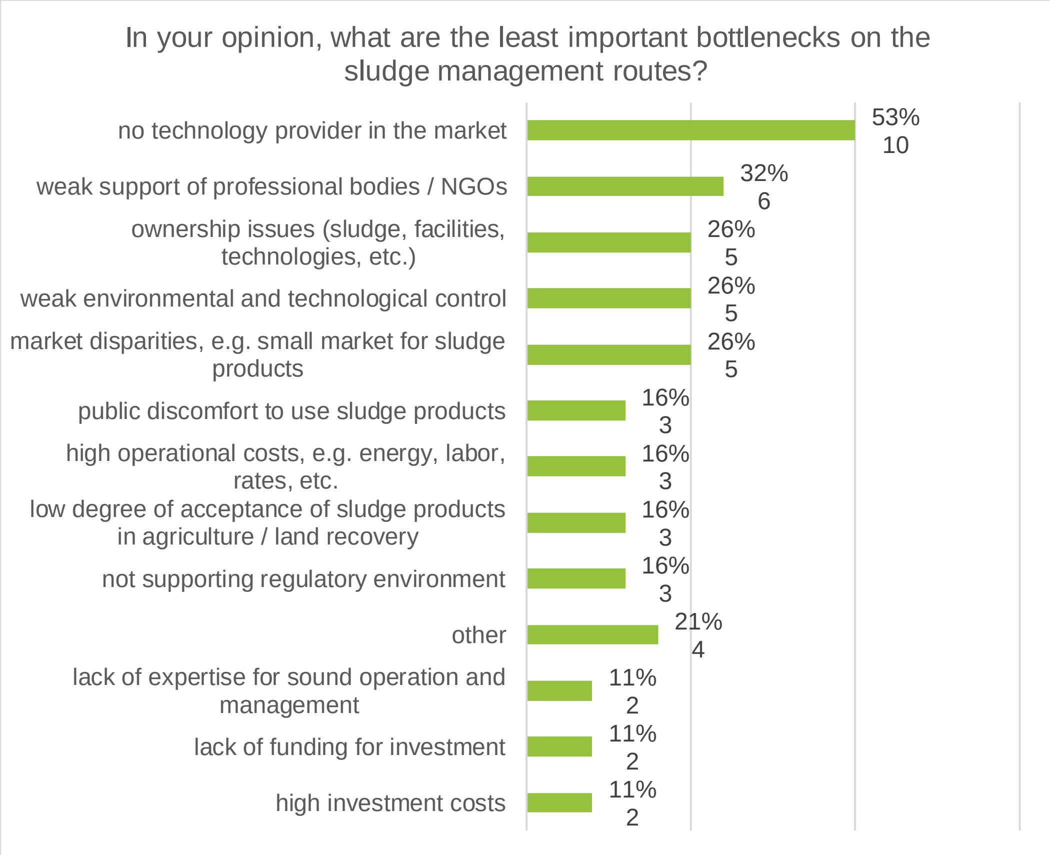
According the responses, feasibility is clearly secured only in the 3.4%n of the cases. In fact, this basically concerns one country, Austria. In this case it is assumed that high recovery fees and environmental levies are set so that they would mirror close to real environmental expenses and the actors in the system are prepared and willing to pay these costs. This means, that in most of the countries of the EUSDR – also in line with the statements related to the regulatory environment – there are considerable limitations in regards to the internalisation of the environmental cost of sludge management.

This issue leads to the weakest point of the sludge management in general, that is financial: according to the responses the better management is clearly hindered by the high investments and operational costs in the sector. Secondly, weak / insufficient regulatory framework is identified as the second most important bottleneck and, again, this is followed by issues at the end of the sludge product line, the attitude of the potential users (agriculture and public), and market issues.  Special concerns were raised in the case the extreme investment costs of incineration and phosphorous recovery, and the issues related to the scale of business; feasible small scale technologies are still missing resulting in market distortions (monopolies of well capitalised operators), higher operational costs, for example, due to high transport costs.

Among the least important bottlenecks within sludge management the availability of the technology was mentioned the most; this means that the technology is available, however, many cases not affordable. According to the answers, usually the actors do not seek the support of professional bodies, and ownership issues are usually well managed during the processes. Interestingly, in many cases market issues were not considered important; this is due to the regulatory obligations of the actors, however, may result in market unbalances.




*26. Figure: The most important bottlenecks of the sludge management processes*




*27. Figure: The least important bottlenecks of the sludge management processes*

## 5.5 The role of the EUSDR in sludge management

The EUSDR plays a special role in promoting the common action and common strategies of the participating countries. The specific roles and the specific actions the EUSDR can take, according to the respondents, are as follows:

- Development of a common, country specific sludge management strategy in line with the EU directives and regulation, considering country / regional specific issues with special emphasis to accession countries; note that sludge management is primarily regulated on the national level
- (participation in the) Development of common standards for the monitoring and measuring of emerging contaminants, organic matter and pathogens
- (Assist the) Organisation of campaigns to engage industry players and agricultural users in the sound management of sludge
- (Assist in) Uniting the markets for sludge management technologies and sludge products
- Regional exchange of best practices;
  - showcases of best practices,

  - support the transfer of technology and knowledge in general and in specific cases
- Support pilot projects and cross-border demonstration plants to operate and present best practices in sludge management with special emphasis on
  - Small scale sludge management
  - Promote research in technological development for low cost solutions for energy and phosphorous recovery, and agricultural use
- (Assist in the absorption of) financial support for projects
- Strengthening regulatory framework; harmonising the efforts of member states
- (Assist in) Increase public and professional awareness related to the use of sludge in agriculture, promote the sustainable use of sludge
- (Support in the) Organisation of trainings and awareness raising campaigns on the new requirements and the best solutions
- Promote strategic actions especially in regards to circular economy, phosphorous recovery and the energetic utilisation of sludge
- (Assist in) The strengthening of the visibility and the representation of the water utility sector

# 6 Best practices

## 6.1 Best available techniques

The Best Available Techniques (BAT) Reference Document for Common Waste Water and Waste Gas Treatment/Management System in the Chemical Sector[33] completed in 2016 discusses the best available techniques for the treatment of wastewater sludge.

The BAT reference document (BREF) is the result of the information exchange among the EU, the waste water treatment operators and the representatives of the industry on member state level. The aim of the document is to collect and propose technical solutions that are in line with the relevant community legislation. The development of the BREF documents takes place under the Industrial Emissions Directive (IED)[34] aiming at the minimising of the pollution from industrial sources.

BAT 13 states that **„in order to prevent or, where this is not practicable, to reduce the quantity of waste being sent for disposal, BAT is to set up and implement a waste management plan as part of the environmental management system (see BAT 1) that, in order of priority, ensures that waste is prevented, prepared for reuse, recycled or otherwise recovered.„** BAT 14 discusses the reduction of the volume of sludge that requires further treatment of disposal and the potential environmental impact. **The best techniques for treatment are as seen in the table below** (29. Table: Best Available Techniques for sewage sludge treatment)**.**

| | Technique | Description | Applicability |
|---|---|---|---|
| **a** | Conditioning | Chemical conditioning i.e. adding coagulants and/or flocculants) or thermal conditioning (i.e. heating) to improve the conditions during sludge thickening/dewatering | Not applicable to inorganic sludge. The necessity for conditioning depends on the sludge properties and on the thickening/dewatering equipment used. |

[33] Best available techniques (BAT) reference document for common waste water and waste gas treatment/management systems in the chemical sector; Industrial Emissions Directive 2010/75/EU (integrated pollution prevention and control); https://op.europa.eu/hu/publication-detail/-/publication/a7e9664c-9ac3-11e6-868c-01aa75ed71a1 https://ec.europa.eu/jrc/en/publication/eur-scientific-and-technical-research-reports/best-available-techniques-bat-reference-document-common-waste-water-and-waste-gas

[34] Directive 2008/1/EC of the European Parliament and of the Council of 15 January 2008 concerning integrated pollution prevention and control; https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX%3A32008L0001

| | Technique | Description | Applicability |
|---|---|---|---|
| **b** | Thickening dewatering | Thickening can be carried out by sedimentation, centrifugation, flotation, gravity belts, or rotary drums. Dewatering can be carried out by belt filter presses or plate filter presses. | Generally applicable. |
| **c** | Stabilisation | Sludge stabilisation includes chemical treatment, thermal treatment, aerobic digestion, or anaerobic digestion. | Not applicable to inorganic sludge. Not applicable for short-term handling before final treatment. |
| **d** | Drying | Sludge is dried by direct or indirect contact with a heat source. | Not applicable to cases where waste heat is not available or cannot be used. |

*29. Table: Best Available Techniques for sewage sludge treatment*

The composition of sewage sludge varies according to many factors, such as system connections, weather, time of year etc. It usually contains phosphorus in the range 1-2,5% dry matter, depending on the wastewater treatment type. Sludge is usually pre-treated before incineration with physical dewatering, drying or sludge digestion.

The Best Available Techniques (BAT) Reference Document for Waste Incineration discusses the applied techniques for the incineration of sewage sludge. The document also mentions phosphorus recovery from sewage sludge incineration ashes. Stationary (or bubbling) fluidised bed incineration is commonly used for sewage sludge treatment, although circulating fluidised bed (CFB) is stated to be the most appropriate way of dried sewage sludge incineration. Phosphorus recovery from sewage sludge is possible from fluidised bed incineration ashes with wet-chemical or thermal process. The range of P-recovery is reported to be between 60-98% for wet-chemical process and 80-98% for thermal process. The process is beneficial for the environment as it reduces the amount of waste for disposal while increasing resource efficiency. In conclusion, sewage sludge incineration can be a sustainable solution, depending on the composition and pre-treatment of the sludge.

## 6.2 Energy recovery from sewage sludge

Whereas digestion is a rather straightforward and widely solution of biogas production and energy recovery from sludge, other more sophisticated, and many times cost intensive methods are receiving growing attention; the issue is now extensively discussed on both policy and professional levels. The technologies that are now in the forefront of discussions are: incineration, pyrolysis and gasification[35].

Incineration involves the combustion of sludge at high temperatures, typically above 850°C, in the presence of oxygen. This method is widely used due to its ability to significantly

[35] A. M. Zaharioiu, F. Bucura, R. E. Ionete, F. Marin, M. Constantinescu and S. Oancea (2021): Opportunities regarding the use of technologies of energy recovery from sewage sludge; In SN Applied Sciences (2021) 3:775

reduce waste volume – by as much as 70-90% – while generating heat and electricity. However, incineration produces ash as a by-product, which can be repurposed in industries like cement manufacturing and road construction. Despite its benefits, incineration faces challenges such as high $CO_2$, NOx, and SOx emissions, as well as the need for advanced pollution control measures. Furthermore, the high moisture content of SS increases the energy required for effective incineration, adding to operational costs.

Pyrolysis is another promising method for energy recovery, conducted in an oxygen-free environment at temperatures between 300–900°C. This process breaks down sludge into three primary products: bio-oil, bio-gas, and bio-char. Bio-oil serves as an alternative to fossil fuels, while bio-char can be utilized for soil enhancement and carbon sequestration. Pyrolysis is favoured for its minimal emissions and ability to reduce heavy metal concentrations in residues. However, it requires significant upfront capital and involves complex chemical reactions. The process also demands energy-intensive moisture removal from SS, which can hinder its economic feasibility.

Gasification offers another route for energy recovery by partially oxidizing sludge to produce synthesis gas (syngas), a mixture of hydrogen, carbon monoxide, and methane. This versatile gas can be used directly for electricity generation or as a feedstock for producing alternative fuels. Gasification is energy-efficient, with conversion efficiencies ranging from 14-30%, and it generates minimal residual waste. However, the process involves significant technological complexity, including syngas cleaning to remove contaminants like tars and heavy metals. Additionally, the high water content in untreated sludge poses challenges to operational efficiency.

Each of these technologies has distinct advantages and disadvantages. Incineration benefits from well-established infrastructure and scalability but faces environmental challenges due to emissions. Pyrolysis is environmentally superior, producing valuable by-products and fewer pollutants, but it remains a costly and technically demanding option. Gasification combines energy efficiency with versatility but requires extensive preprocessing and advanced gas-cleaning systems.

In conclusion, energy recovery from SS is an effective strategy for waste management and renewable energy production. Among the options, pyrolysis stands out for its environmental benefits and diverse applications, though it requires further cost and efficiency improvements to achieve widespread adoption. Gasification offers high energy efficiency but is limited by its complexity and costs, while incineration remains a reliable but less sustainable choice. Advancing these technologies through innovation in preprocessing, cost reduction, and emission control will be critical to maximizing their potential for global adoption.

## 6.3 Good practices for utilisation

The present section gives an insight into the most promising technologies and techniques in sludge management. Whereas there is a growing concern for energy recovery from sludge, agricultural utilisation of sludge and sludge products is still a viable option for many countries worldwide and within the Danube Region. Thus, the examples drawn here aim to help the understanding of the various technological possibilities that already exist and point out the fact that even though there are a number of available technologies, still the tailoring of the solutions to the specific conditions of each region, or even each treatment plant, is still an important element of the sludge management processes.

The last two cases are of Sweeden and the Netherlands, both having long traditions in the agricultural use of sludge and both facing now restrictions in this type of nutrient recovery. In both countries there have been debates on the proper management of sludge and following environmental considerations, incineration and other more technology-intensive solutions were / are being put forward. As these solutions are many times expensive and shall be paired with flexible economies, their application may be questionable in many Danube Region countries, however, in the future, all countries will have to face these strategy debates due to changing technological and market conditions, as well as tightening environmental standards.

**ECO-BIS – Developing more environmentally-friendly and efficient waste water treatment plants and recycling sewage sludge into a high added value biochar material[36]**

Introduction of new ways of wastewater treatment, sewage sludge handling is encouraged in the EU to reduce volumes of current main disposal routes of municipal waste, sludge as they have a serious environmental impact. The EU legislation requires Member States to treat wastewater and sludge nevertheless the heavy metal content and other pollutants (pathogenic organisms, hormones, etc.) still pose an environmental threat.

The ECO-BIS project aiming at more environmentally friendly treatment and turning sludge into biochar material (high value carbon-phosphorus fertiliser) is an innovative initiative which saves energy and reduces GHG emission in the process of treatment.

In a three-year period between 2013 and 2016 under the Eco-innovation initiative of the EU three ECO-BIS plants were established using the technology developed by Greenlife RESSOURCEN GMBH, Austria that coordinated the project. The three ECO-BIS plants were established In Hungary, Slovenia and Austria with an overall budget of the project amounted to over EUR 2.4 million with an EU contribution of 50%

The energy efficient technology is based on a process made up of three main steps of pre-cleaning, dewatering and carbonising. In step one energy-rich sludge is produced by reducing 70 percent of the chemical oxygen demand (COD). As a result, the energy demand to aerate in biological treatment becomes much lower saving considerable costs too. Then the water content is reduced by a vacuum filter which is more efficient than the traditional ways. The result is high dry matter content in addition to less than 1 $kWH/m^3$ energy consumption. The material is now ready to be carbonised by pyrolysis to produce a clean and valuable nutrient rich carbon-phosphorus fertiliser. The following figure shows the process step by step:

[36] ECO-BIS.eu - Home (eco-bis.eu)


*28. Figure: The process of ECO-BIS technology*

Besides energy and GHG emission savings, the other benefit is that the costs of disposal are minimized: 4000 tons of dewatered sludge turns into 500 tons of marketable product also diverting wet sludge from landfilling.

Since there are over 50 thousand wastewater treatment plants in the EU, this innovative technology can be an attractive alternative to the traditional wastewater treatment practices contributing to the achievement of EU environmental and climate change objectives, higher compliance with current waste management regulations.

**ECO SLUDGE – Economically viable solution for the energy autarkic (self-sustaining) treatment of sewage sludge to multi usable ash**

The project co-ordinated by Kalogeo Anlagenbau GmbH, Austria specialised in decentralised treatment of sewage sludge and wastewater was implemented between 2009-2012 partly on response to changing sludge strategies in some of the EU countries. Some 35% of the total cost of EUR 2.2 million was funded by the EU under the cross-cutting Eco-Innovation initiative managed by EACI. The project was implemented in partnership with three other companies including the German power supplier EON Kraftwerke Gmbh.

The process of mono-combustion process of treating sewage sludge includes two main steps: pre-drying of sludge and thermal utilisation that produces energy for pre-drying through the innovative heat recovery process.

This new solution ensures that the product from treated sewage sludge is free from hazardous residuals such as hormones, heavy metals, etc. This inert ash can be used as a substitute in the cement industry and enables phosphorous recovery for the fertiliser industry. This innovative technology has another benefit: in addition to being energy self-sufficient it produces energy surplus in a cost-efficient way. This energy can be used in the district heating network or fed to the grid when transformed into electricity.

The annual performance, output of the plant including savings through multiple application of the ashes are as follows (30. Table: Performance indicators for the experimental plant):

| | Annual performance, benefits |
|---|---|
| **Plant capacity** | 24,000 tons |
| **Reduction of gas consumption** | 677,500 m3 |
| **Surplus energy** | 7,500 MWh |
| **$CO_2$ reduction** | 1,500tons |
| **Inert ash** | 3,200 tons |
| **$CO_2$ savings due to use in cement industry** | 2,400 tons |

*30. Table: Performance indicators for the experimental plant*
*Source: Kalogeo process*[37]

## ENERCOM - Treating sewage sludge intelligently

The project, ENERCOM (ENERgy from COMpost) in short, was a European project under FP7 for the establishment of a polygeneration plant applying an innovative technology to recover sewage sludge and green waste. The technology was developed, and the plant was built by the Soil-Concept S.A in a consortium with the participation of six other international SMEs and educational institute from Germany, Austria, Belgium, Luxemburg and Lithuania. The project with an overall cost of over EUR 5.2 million received funding of EUR 2.5 million under FP7-Energy in 2008-2013. The polygeneration pilot plant was established in Diekirch, Luxembourg at the site of an existing compost production facility, an ideal site, inter alia, to reduce transportation costs.

The main idea of the innovative technology is that the polygeneration plant is jointly composting sewage sludge and green waste with the purpose to generate renewable energies both thermal and electric. The sophisticated processes of thermal treatment, combination of fluidised bed combustion and gasification allows for effective recovery of municipal waste, sewage sludge with minimising greenhouse gases and maximising energy output. Using low temperature environmental heat, applying efficient gasification process it achieves overall energy efficiency.

Polygeneration technology produces renewable energy, syngas (synthetic gas) as a fuel while producing pellets from sewage sludge biomass substrate that provides a source of energy. It is a flexible, safe, cost-effective way of waste disposal, recycling which can be considered an alternative to current disposal routes. In addition, it is more cost-effective and helps to avoid environmental impacts, contributes to achieving waste management targets.

The plant produces electricity that is fed to the grid while heat is used on site for drying. The final products also include high-value compost, fertilisers as the minerals, nutrients are recovered from the ash and added to improve value of compost. Of course, heavy metals and other pollutants are also removed to ensure quality product and to fulfil regulatory requirements.

It is considered a cutting-edge technology as both generation of renewable energy and sludge disposal are growing markets. As it also supports compliance with EU regulations

[37] Kalogeo process: Economically viable solution for the energy autarkic treatment of sewage sludge to multi usable ash (ECO SLUDGE); http://www.act-clean.eu/index.php?node_id=100.349

on sewage sludge, waste treatment and agricultural application of sludge products it has been foreseen to have good potentials in any sludge or organic matter treatment plant (over 3000 plants across the EU). With this in mind, a spin-off SME was established for the core activity of planning and marketing such plants.

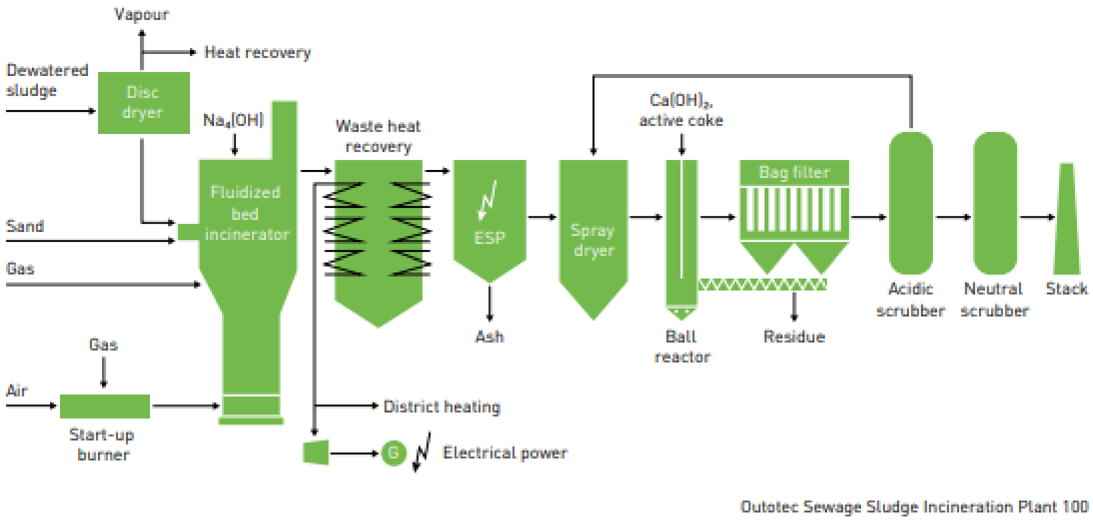
### Outotec Sewage Sludge Incineration Plant, Switzerland

Outotec Sewage Sludge Incineration Plant completed in 2015 with a total investment cost of CHF 20 million treats all the sewage sludge produced in Zürich Canton, Switzerland. Outotec's technology is an incineration solution developed to replace costly sludge disposal and to recover valuable phosphorous content. In fact, project costs are recovered by the sludge disposal fees; the applied technologies greatly rely on the results of the ECO SLUDGE project.

The plant in Werdhölzli owned by the City of Zürich has a favourable location for transport logistics. It is designed to treat all sludge from the canton area through 2035. It has the capacity to treat 100,000 metric tons of dewatered sewage sludge annually.

The Outotec incineration process, the fluidised bed technology and gas treatment procedure enables the plant to be self-sustaining. As the figure below shows the main technological steps are as follows:

- Sludge collected in a bunker where it is mixed
- It is partly dried by steam and fed to a fluidised bed incinerator (FB)
- Vapourised water is condensed, heat fed to the district heating system
- Reducing NOx emissions with selective non-catalytic reaction
- The flue gases used to produce steam in boiler system and released after de-dusting and application of additives
- 99% of the ash is separated in an electrostatic precipitator




*29. Figure: The technological chain of the incinerator plant*

*Source: OUTOTEC, 2020*[38]

The plant runs practically without using external electricity (except for the start-up), the turbines generate enough electricity for operation and an additional 5MW to the district heating system. Minimal environmental impact is achieved by cleaning the flue gas resulting in considerable reduced emission values as follows (31. Table: Emission of flue gas):

| | Emissions (per m3 STP dry flue gas) |
|---|---|
| **Dust** | < 10 mg |
| **Pb+Zn** | < 1 mg |
| **Hg** | < 0.1 mg |
| **Cd** | < 0.1 mg |
| **$SO_2$** | < 50 mg |
| **NOx** | < 80 mg |
| **HCl** | < 10 mg |
| **HF** | < 1 mg |
| **$NH_3$** | < 5 mg |
| **CO** | < 50 mg |
| **PCDD/PCDF** | < 0.1 ng TEQ |

*31. Table: Emission of flue gas*
*Source: OUTOTEC, 2020*

In addition to energy, the produced ashes are rich in phosphorous that can be converted into fertiliser which is a future potential for the plant with the Outotec ASHDEC technology. Depending on feedstock incinerated the ash can be free of pollutants, however sewage sludge being highly impure is to go through thermo-chemical processing by the ASH DEC technology before it can be used as phosphate fertiliser. The ashes are mixed with alkaline additives and heated to 800-1000 °C to produce biodegradable phosphate compounds and remove heavy metals.

The lowest environmental footprint is achieved when it is vertically integrated with the sludge incinerator sharing a number of components to cut back Capital Expenditures and Operating Expenses alike.

### Debate on the sludge management strategy – the Swedish case[39]

Sweden has a long history in sludge management as the country accelerated the development of its waste water treatment plants already after World War II. In the 50s and 60s agricultural recovery of sludge was an obvious and widespread solution to the sludge problem, however in the 70s an ever-growing intensity discussion started on agricultural

[38] https://www.outotec.com/products-and-services/technologies/energy-production/sludge-incineration-plant/
[39] L. Dagerskog and O. Olsson (Swedish Environmental Institute, SEI) (2020): Swedish sludge management at the crossroads; SEI policy brief
N. Johansson (KTH Royal Institute of Technology) (2018): How can conflicts, complexities and uncertainties in a circular economy be handled? A cross European study of the institutional conditions for sewage sludge and bottom ash utilization; KTH Report from the division for Strategic sustainability studies;

recovery due to environmental concerns. During the debates it was revealed that the amounts of nutrients found in sludge can substitute a considerable part of the overall nutrient demand of agriculture (32. Table: The nutrient use of the Swedish agriculture and the potential of sludge for substitution):

| | Used in fertilizer (thousand t/yr) | In sludge (% of current fertiliser use) |
|---|---|---|
| **Nitrogen** | 186 | 5 |
| **Phosphorus** | 13.1 | 42 |
| **Potassium** | 26,5 | 3 |

*32. Table: The nutrient use of the Swedish agriculture and the potential of sludge for substitution*
*Source: SEI, 2020*

The long debate seemed to be settled through the strict revision of the standards under which sludge can be used as fertiliser in agriculture, setting contaminant limits for sludge and sludge products and calling for the reduction of contaminants in waste water (REVAQ). It is recommended that sludge from the REVAQ-certified WWTPs shall be reused in agriculture that makes up around the 45% of all sludge produced in the country. Still, however, due to the growing concern for clean agricultural product, some mills and food industry plants in Sweden refuse to use agricultural products from farmland where sludge is used on land (33. Table: Contaminants related to the agricultural use of sludge).

| | Sludge content mg/kg | Background level in arable land; mg/kg | Surplus due to sludge; gr/ha |
|---|---|---|---|
| **Cadmium (Cd)** | 2 | 0.4 | 0.75 |
| **Copper (Cu)** | 600 | 40 | 300 |
| **Mercury (Hg)** | 2.5 | 0.3 | 1.5 |
| **Chrome (Cr)** | 100 | 60 | 40 |
| **Lead (Pb)** | 100 | 40 | 25 |
| **Nickel (Ni)** | 50 | 30 | 25 |
| **Zinc (Zn)** | 800 | 100 | 600 |

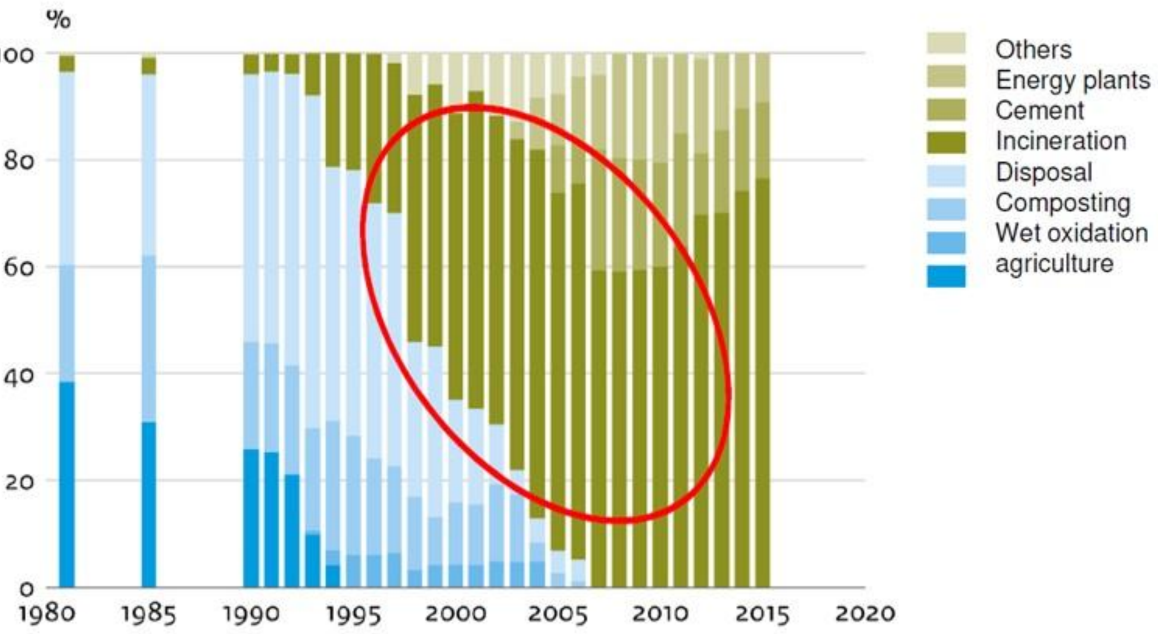
*33. Table: Contaminants related to the agricultural use of sludge*
*Source: SCS, 1998; Naturvårdsverket, 1994 in KTH, 2018*

Critics against the system also emphasise that many “emerging” pollutants, such as pharmaceuticals, micro-plastics and micro-pollutants are not covered in the REVAQ standards, however their quantities are increasing according to recent measurements.

The other dimension of the debate is the EU-wide spreading practice of incineration of sludge and the phosphorous removal from ash. It has been calculated that an amount of 75 kWh/yr/person connected (equalling to 0.5% of per capita energy consumption of Sweden but almost to 2% of the per capita energy consumption of Hungary roughly with the same population of 10 million persons note that Sweden runs a far more energy demanding economy than Hungary). Still, Sweden is now relying on agricultural recovery and composting and the alternative recovery techniques (under the label “other”) make up a considerable part of sludge recovery. It has been recognised that the phosphorous removal from the ash of incinerated sludge is technologically solved, however expensive and it also eliminated the problem of the contaminants present is sludge / compost. It has been forecasted, if the government would ban or set stricter standards for agricultural recovery, incineration is going to become dominant in sludge management. Also, it was highlighted that with this option the efforts for the reduction of the quantity of sludge as well as incentives to decrease upstream environmental loads on WWTPs (i.e. decreasing loads to the sewage and runoff water) will be in vain. It was also debated whether the phosphorous removal solves the nutrient issue by itself; the nitrogen and potassium content of sludge is also relatively high and as Sweden relies on import concerning fertilisers, the utilisation of the existing resource would be feasible.

### The Dutch practice

The Netherlands is a small, densely populated downstream country with high-end water management practices and viable agriculture. The country, being poor in resources, however, banned the agricultural use of sludge by decree in 1995 and considerably limited disposal in 1997. Thus, since the late 1990s there has been a clear shift in the recovery of sludge in the country[40]:




*30. Figure: Sludge management trends in the Netherlands*
*Source: in A. Ruijter, 2018*

As it can be seen from the trends, the country relies on different kinds of thermal/energetic recovery techniques, however some end-products of the sludge recovery processes are utilised by agriculture. The country treats approx. 1.5 million tonnes of sludge yearly, and the dewatered and partly composted sludge is incinerated in regional plants or co-incinerated in the cement or energy industry; a great part of the sludge is recovered in the cement industry and mainly used in road construction.

When the nutrient recovery was considered, Dutch studies estimated that phosphorous content of the residual ashes amounts to 14 thousand tonnes of phosphorus pentoxide ($P_2O_5$; a precursor a phosphorous fertilisers) per year. The Dutch system utilises the struvite

[40] A. Ruijter (2018): Dutch experience of sludge management and P-recovery pathways; Environ 2018/Phos4You presentation

(magnesium ammonium phosphate; $NH_4MgPO_4 \cdot 6H_2O$) and the ash routes for phosphorous removal: in the sludge digestion process and amount of 2500 tonnes of struvite is produced yearly that is used as a fertiliser directly or mixed in agriculture, however, in this case strict pathogenic control is required; in the ash route 57 thousand tonnes ash is produced with a 27% of phosphorus pentoxide content, this material can be traded under waste status, contains no pathogens and is an important part of the fertiliser industry of the Netherlands, in addition the ash serves as a source of aluminium and iron salts.

The sludge recovery plant of North-Brabant (Slibverwerking Noord-Brabant; SNB) is one of the main centres of the Dutch system; it handles 1.5 thousand tonnes of sludge (50 trucks) each day. After mixing and drying the material enters the oven equipped with flue gas cleaners. During the process steam is produced that is used for drying sludge and other technological steps, and partly for electricity production. The flue ash is trapped by electrostatic filters, and the flue gas is washed (cold wash and alkaline washing) and cloth filtered (primarily concerning mercury) to be cleaned from other pollutants; a part of the $CO_2$ is also captured and is traded to a manufacturer of lime products. The residing ash is considered as a raw material for further processes; it is estimated that around 95% of the ash, meaning 0.03% of the sludge itself, can be reused and the rest is landfilled. The plant is basically energy neutral.

The relative vulnerability of the system and the seriousness of quality issues was revealed in a recent incident[41]. After the failure of the Amsterdam waste incineration plant, an agreement between the UK and the Netherlands was signed on the export of 27.5 thousand tonnes of dewatered municipal sludge for agricultural recovery. The need for such an agreement showed that in case of any unexpected events, the strict regulation and available premises of sludge storage result in a situation where solutions have to be developed quickly and that may not be most feasible and safe. The report of the UK authorities on the quality of the exported sludge showed, as revealed by Unearthed (Greenpeace UK's journalism project), that the sludge imported to the UK is contaminated with microplastics, weedkillers (herbicides), and persistent organic pollutants, like dioxins, furans, and polycyclic aromatic hydrocarbons at "levels that may present a risk to human health". This issue drew attention to the fact the UK greatly relies on agricultural sludge recovery, however, quality issues are not the best covered as also discussed by the policy paper issued by the UK Environment Agency strategy for safe and sustainable sludge use (July 2020)[42].

## 6.4 The case of the North-Budapest Waste Water Treatment Plant[43]

The North-Budapest Waste Water Treatment Plant shows an example of a relatively low cost, still feasible solution to sludge management as well energy and nutrient recovery. The

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[41] https://unearthed.greenpeace.org/2020/09/02/uk-imports-sewage-sludge-agriculture/
https://www.euronews.com/2020/09/07/uk-imports-tonnes-of-dutch-sewage-sludge-for-agricultural-benefit-sparking-toxicity-concer

[42] https://www.gov.uk/government/publications/environment-agency-strategy-for-safe-and-sustainable-sludge-use

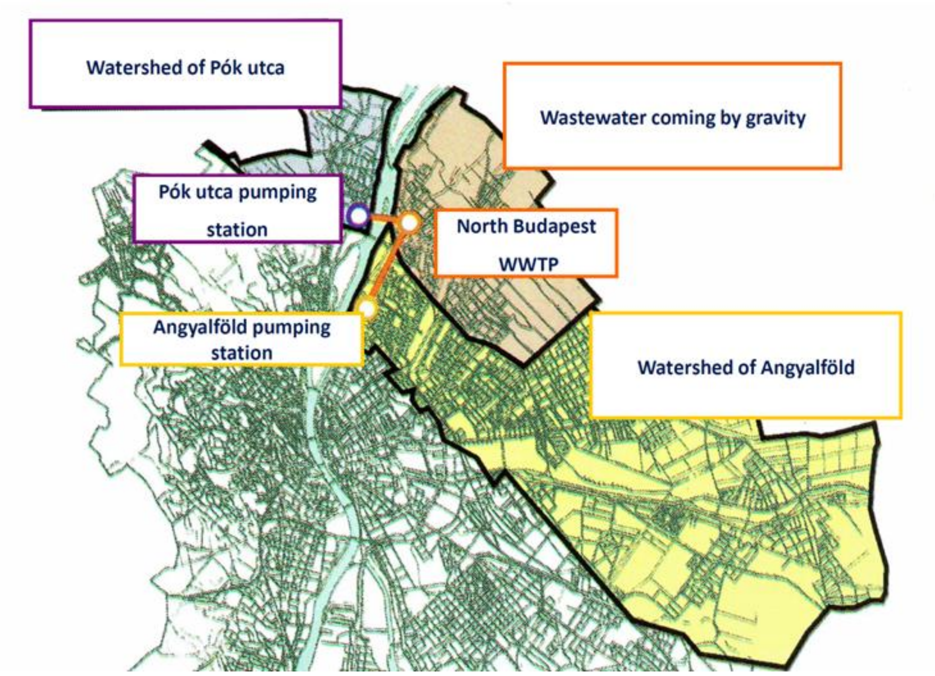
[43] The contribution of the Budapest Sewage Works Pte Ltd. and primarily of the colleagues of the Environmental directorate and the North-Pest sewage plant is greatly appreciated; data and information presented in this section were provided by the Budapest Sewage Works Pte Ltd.

plant was developed jointly from EU, national and municipal sources into one of the largest treatment plants in Hungary, with advanced technologies. In line with the Hungarian Sludge Management Strategy, it applies energy recovery through digestion and the agricultural utilisation of dewatered and treated sludge. The plant is operated by the Budapest Sewage Works Pte Ltd., that is owned by the Municipality of Budapest and is controlled by national environmental authorities.

The North-Budapest Waste Water Treatment Plant collects the wastewater of the IV., XV., XVI., XVII. districts, and partly of the III., X., XIII., and XIV. Districts of Budapest and some of the neighbouring agglomeration. The plant has a treatment capacity of 200th $m^3$ per day and treats an average of 130 th $m^3$ of wastewater per day. The wastewater treatment plant operates with environmentally friendly, complex purification and waste treatment, as well as utilization technology. During the purification of wastewater, 1500 $m^3$ of inorganic waste and 50th $m^3$ of dewatered sludge are generated annually.

In addition to the treatment of wastewaters arriving through the sewage system, the plant is involved in the other activities, such as:

- Treatment of the sewage sludge from the Budapest sewer network
- Environmentally friendly treatment of by-products, such as sludge and mechanical impurities generated
- Assisting in rainwater and flood management
- Produces energy
- Organic waste management:
    1. liquidous wastes
    2. dewatered sludge
    3. animal waste
    4. other organic waste (e.g. food waste)




*31. Figure: The operational area of the North-Budapest WWTP*

### The technological processes

The North-Budapest Wastewater Treatment Plant begins its process by receiving raw sewage partly through gravity-fed (northern Budapest), and partly through pressurized (western/Pók str. pumping station and east-central areas/ Angyalföld pumping station) pipelines. Mechanical treatment is the first stage, where coarse debris is removed using screens with a 5 mm bar spacing. Following this, the wastewater passes through six grit and grease chambers, which separate sand and grease from the flow. The mechanically treated water then enters four primary sedimentation tanks of the SEDIPAC type, each designed with a total volume of 4,600 m³, where settleable solids are removed, ensuring that only finer particles and dissolved materials progress to the next stages.

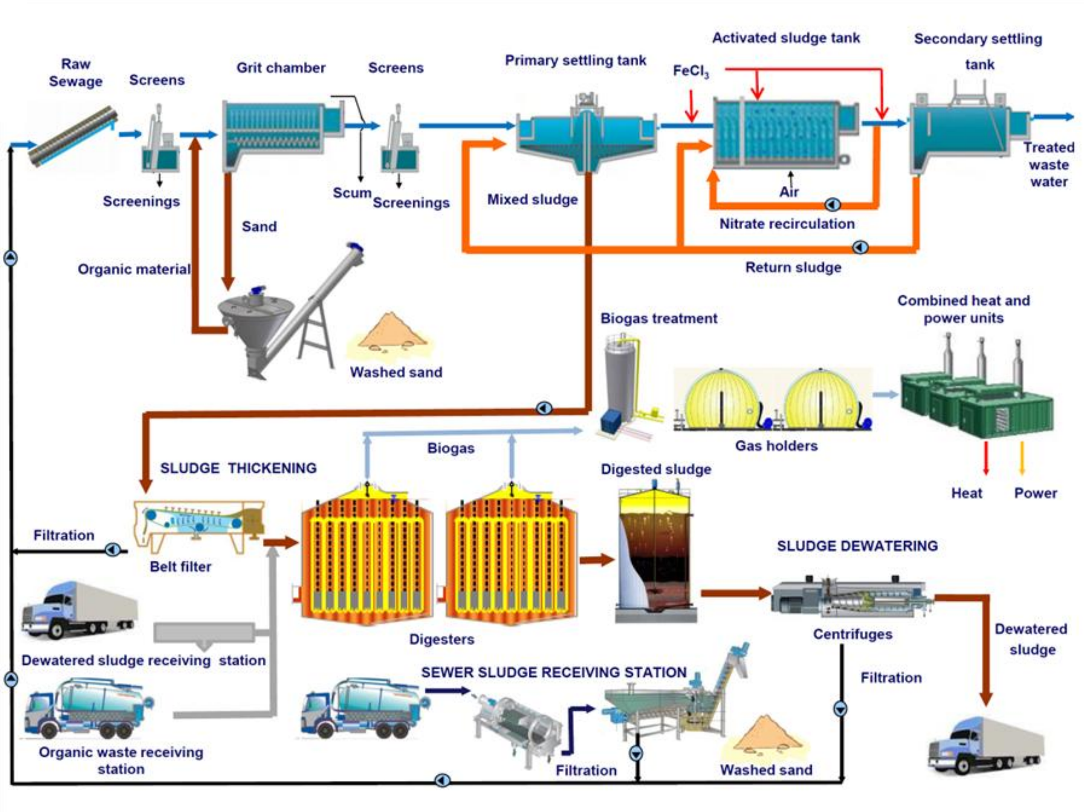
The biological treatment process utilizes activated sludge technology to further purify the wastewater. It is divided into anoxic and aerobic zones to facilitate biological nitrogen removal through denitrification and nitrification processes. The system uses periodic aeration and internal nitrate recirculation to enhance nitrogen removal efficiency. The treated water then enters final settling tanks to allow the separation of treated effluent from the sludge. "A" line has four parallel tanks with a total volume of 30,800 m³, while "B" line has eight tanks with a combined volume of 23,000 m³. Both lines use chain scrapers to optimize sludge removal.

The plant also is involved with the treatment of special industrial waste waters upon contracts with industrial producers; these wastes arrive to the plant by vehicles. Such waste waters are treated, if necessary, according to their specific components and later enter the overall treatment process. Other industrial waste waters are pre-treated at the industrial sites and if the quality of the effluent permits, they are also drained to the system.

To ensure the removal of phosphorus, ferric chloride ($FeCl_3$) is introduced into the system. Online monitoring systems measure key parameters such as ammonium, nitrate, phosphate, and dissolved oxygen levels, enabling real-time adjustments for optimal treatment conditions. This precise control helps the plant meet stringent water quality requirements for effluent discharge.

The sludge extracted during sedimentation undergoes thickening. The thickened sludge is then fed into two anaerobic digesters. The biogas is then treated utilized in gas engines, which convert it into heat and electricity. In the post-digestion phase, the sludge undergoes dewatering increasing dry matter content. Approximately 900–1,000 m³ of sludge is processed daily, conditioned with polyelectrolytes to enhance efficiency. The dewatered sludge, amounting to over 40,000 tons annually, is transported for composting, contributing to sustainable waste management practices.

The final stage ensures that treated water meets stringent regulatory limits for pollutants. The effluent leaving the plant is thus safe for discharge into the environment, underscoring the plant's commitment to environmental protection and public health.




*32. Figure: The technological flow in the North-Budapest WWTP*

The technological flow provides for the efficient cleaning of sewage and waste waters arriving from the catchment area. The chemical compositions of the influent and effluent water are presented in the below tables (34. Table: Chemical composition of influent waters and 35. Table: Chemical composition of influent waters):

| Year | Chemical oxigen demand | pH | Total suspended solids | Mineral suspended solids | Total P | NH4-N | NO2 | NO3 | Extract-able by hexan | Fenol-index | TKN | Total N | Toal organic N | Bio. oxygen demand 5 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | [mg/l] | [-] | [mg/l] | [mg/l] | [mg/l] | [mg/l] | [mg/l] | [mg/l] | [mg/l] | [mg/l] | [mg/l] | [mg/l] | [mg/l] | [mg/l] |
| **2018** | 679 | 7,6 | 379 | 85 | 10,4 | 58,6 | 0,33 | 1,0 | 19,1 | 0,13 | 77 | 77 | 18,3 | 380 |
| **2019** | 825 | 7,8 | 520 | 127 | 13,3 | 57,4 | 0,24 | 0,7 | 22,2 | 0,12 | 82 | 83 | 25,0 | 426 |
| **2020** | 631 | 8,0 | 355 | 95 | 9,2 | 57,9 | 0,36 | 0,8 | 18,9 | 0,08 | 74 | 75 | 16,3 | 359 |
| **2021** | 600 | 8,0 | 305 | 80 | 7,8 | 55,5 | 0,67 | 0,8 | 21,1 | 0,08 | 71 | 71 | 15,3 | 357 |
| **2022** | 675 | 8,0 | 338 | 87 | 9,0 | 60,4 | 0,23 | 0,6 | 20,1 | 0,07 | 77 | 77 | 15,7 | 384 |
| **2023** | 561 | 8,0 | 284 | 68 | 8,3 | 53,7 | 0,20 | 0,8 | 23,2 | 0,07 | 67 | 67 | 13,1 | 331 |

*34. Table: Chemical composition of influent waters*

| Year | Chemical oxigen demand | pH | Total suspended solids | Mineral suspended solids | Total P | NH4-N | NO2 | NO3 | Extract-able by hexan | Fenol-index | TKN | Total N | Total organic N | Bio. oxygen demand 5 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | [mg/l] | [-] | [mg/l] | [mg/l] | [mg/l] | [mg/l] | [mg/l] | [mg/l] | [mg/l] | [mg/l] | [mg/l] | [mg/l] | [mg/l] | [mg/l] |
| **2018** | 38 | 7,6 | <10 | <10 | 0,88 | 3,97 | 1,1 | 33,80 | <2 | <0,05 | 5,7 | 13,6 | 2 | 11 |
| **2019** | 40 | 7,7 | 11 | <10 | 0,75 | 1,87 | 0,7 | 25,06 | <2 | <0,05 | 4,0 | 9,9 | 2 | <10 |
| **2020** | 31 | 7,7 | <10 | <10 | 0,74 | 2,58 | 1,4 | 31,73 | <2 | <0,05 | 4,1 | 11,7 | 2 | <10 |
| **2021** | 31 | 7,7 | <10 | <10 | 0,80 | 3,77 | 1,2 | 28,11 | <2 | <0,05 | 5,2 | 11,9 | 2 | <10 |
| **2022** | 29 | 7,8 | <10 | <10 | 0,60 | 3,80 | 1,2 | 26,95 | <2 | <0,05 | 5,2 | 11,6 | <1 | <10 |
| **2023** | 27 | 7,7 | <10 | <10 | 0,94 | 3,13 | 1,3 | 34,50 | <2 | <0,05 | 4,0 | 12,1 | <1 | <10 |

*35. Table: Chemical composition of influent waters*

All compounds are monitored regularly within the own laboratory of the plant and samples are sent to the authorities as described in the line legislation. No violation of the thresholds were reported during the last 15 years of operation of the plant. The monitoring of the emerging pollutants is not included into the monitoring process and no ad-hoc measurements have been performed to asses the presence in the sludge.

## Sludge treatment and recovery

The sludge treatment process at the North-Budapest Wastewater Treatment Plant is involved with the treatment of the sludge produced in the plant itself. Other organic matters, such as organic waste and sewerage sludge arriving to plant are treated by dedicated technologies. The process concerning the produced sludge starts with thickening, where mixed sludge, containing 2–4% dry solids (DS), is processed to increase its solid concentration. This is achieved using three belt thickeners, which reduce the water content of the sludge, producing a thickened sludge with a dry solids content of 5–7%. Thickening is an essential step in minimizing the volume of sludge to be handled in subsequent stages, making the entire process more efficient and cost-effective. In the case of wastes and other organic materials (primarily sewerage sludge) a pre-treatment of wastes is conducted if necessary and the pre-treated organic waste is mixed with the thickened sludge.

*33. Figure: Sludge thickenning in the North-Budapest WWTP*

The thickened sludge is directed to the plant's anaerobic digesters, which are a critical part of the treatment process. These digesters operate at a controlled average temperature of 36.5°C, facilitating the microbial breakdown of organic material in the absence of oxygen. The plant houses two digesters, each with a volume of 12,000 $m^3$. The sludge remains in the digesters for a hydraulic retention time (HRT) of 20–25 days, during which volatile organic compounds are converted into biogas – a mixture of methane and carbon dioxide. This step not only reduces the organic content of the sludge but also stabilizes it, making it safer for further handling and disposal.

Anaerobic digestion produces biogas as a valuable byproduct. The biogas is subjected to a multi-step treatment process to ensure its usability. It is first purified through gravel filters to remove particulate matter, followed by hydrogen sulfide removal to reduce corrosive components; the gas is then filtered through ceramic filters. The gas is then passed through active carbon adsorbers for final purification. Treated biogas is stored in two double-membrane gas reservoirs, each with a capacity of 2,720 $m^3$.  The purified biogas is used to generate energy through gas engines.

*34. Figure: Anaerob digesters and gas sotarage tansk in operation*

*35. Figure: Gas engines utilsing biogas*

Following digestion, the stabilized sludge undergoes dewatering to further reduce its water content. Four centrifuges, two of which are new and one modified, are used to dewater approximately 900–1,000 m³ of sludge daily. This process increases the dry solids content to 24–26%, significantly reducing the volume of sludge that needs to be transported or disposed of. To enhance dewatering efficiency, the sludge is conditioned with polyelectrolytes, which help separate water from solids more effectively.


*36. Figure: Dewatering in the North-Budapest WWTP*

The dewatered sludge is transported to external facilities for composting, where it is recycled as a soil amendment or organic fertilizer. In 2023 alone, the plant produced approximately 40,854 tons of dewatered sludge.

*37. Figure: Transportation of dewatered sludge at the North-Budapest WWTP*

The effective sludge treatment provides for the breakdown of most of the hazardous organic matter and the result is a good quality organic matter with moderate pollutant content meeting the national and community thresholds (36. Table: Chemical composition of dewatered sludge / heavy metals and 37. Table: Chemical composition of dewatered sludge / organic compounds):

| Year | Mercury | Zinc | Arsene | Cobalt | Cadmium | Copper | Lead | Nickel | Chromium | Selen | Potassium | Molyb-denum |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | mg/kg | mg/kg | mg/kg | mg/kg | mg/kg | mg/kg | mg/kg | mg/kg | mg/kg | mg/kg | mg/kg | mg/kg |
| **2018** | 0,66 | 612 | 6,7 | 4,83 | 2,68 | 326 | 37,6 | 29,2 | 21,5 | 2,7 | 2342 | 8,0 |
| **2019** | 0,81 | 881 | 3,4 | 2,86 | 1,98 | 335 | 32,4 | 28,6 | 35,7 | 3,6 | 3180 | 5,4 |
| **2020** | 1,05 | 715 | 5,9 | 3,40 | 0,88 | 318 | 29,4 | 25,1 | 48,7 | 1,6 | 2092 | 5,5 |
| **2021** | 0,92 | 721 | 5,7 | 3,07 | 0,84 | 324 | 29,6 | 27,9 | 39,6 | 2,0 | 2161 | 5,8 |
| **2022** | 0,92 | 708 | 6,5 | 3,06 | 0,75 | 334 | 26,7 | 32,6 | 25,7 | 2,7 | 1500 | 5,7 |
| **2023** | 0,50 | 708 | 5,9 | 3,28 | 0,74 | 312 | 27,1 | 30,6 | 28,6 | 3,0 | 1242 | 5,4 |

*36. Table: Chemical composition of dewatered sludge / heavy metals*

| Year | pH | Total dry matter | Annealing residues | Annealing loss | Phosphourous | Nitrogen | TPH | Total PAH | Organic dissolution extract |
|---|---|---|---|---|---|---|---|---|---|
| | [-] | g/kg | g/kg | g/kg | g/kg | g/kg | g/kg | g/kg | g/kg |
| **2018** | 9,6 | 291 | 163 | 129 | 29,3 | 37,4 | 1891 | 1249 | 19,4 |
| **2019** | 8,4 | 238 | 91 | 147 | 26,6 | 47,5 | 2287 | 1477 | 17,5 |
| **2020** | 8,5 | 256 | 112 | 145 | 28,1 | 41,0 | 3950 | 2188 | 17,5 |
| **2021** | 8,5 | 265 | 115 | 150 | 27,6 | 42,2 | 3085 | 1703 | 20,6 |
| **2022** | 8,6 | 227 | 92 | 135 | 29,5 | 43,0 | 3765 | 1286 | 22,3 |
| **2023** | 8,6 | 248 | 108 | 140 | 30,0 | 42,3 | 3655 | 1568 | 33,5 |

*37. Table: Chemical composition of dewatered sludge / organic compounds*

All compounds are monitored regularly withing the own laboratory of the plant and samples are sent to the authorities as described in the line legislation. No violation of the thresholds were reported during the las 15 years of operation of the plant. The monitoring of the emerging pollutants is not included into the monitoring process and no ad-hoc measurements have been performed to asses the presence in the sludge.

### Energy recovery

The North-Budapest Wastewater Treatment Plant integrates advanced energy recovery systems to minimize energy consumption while maximizing self-sufficiency. By leveraging biogas generated during sludge treatment and implementing efficient energy utilization technologies, the plant achieves remarkable sustainability and operational cost savings. In 2023, the facility reached an energy self-sufficiency rate of 91.9%, exemplifying its innovative approach to sustainable wastewater treatment. The energy self-sufficiency of the plant and the connected other facilities, such as pumping stations, was achieved through the biogas-to-energy conversion process supplemented with the energy produced by a 400kWp capacity solar power plant.

Energy recovery begins in the sludge treatment process, where anaerobic digesters play a central role. These digesters, each with a capacity of 12,000 $m^3$, operate at an optimal temperature of 36.5°C and a hydraulic retention time (HRT) of 20–25 days. During this process, microorganisms break down organic material in the sludge, producing biogas, a renewable energy source primarily composed of methane and carbon dioxide. The production of biogas not only stabilizes the sludge but also provides a continuous supply of energy-rich gas for the plant.

The raw biogas generated in the digesters undergoes a thorough purification process before utilization. This includes:

- Gravel and Ceramic Filtration: removal of particulate impurities.
- Hydrogen Sulfide Removal: elimination of corrosive components to protect downstream equipment.
- Active Carbon Adsorption: further purification to meet quality standards.

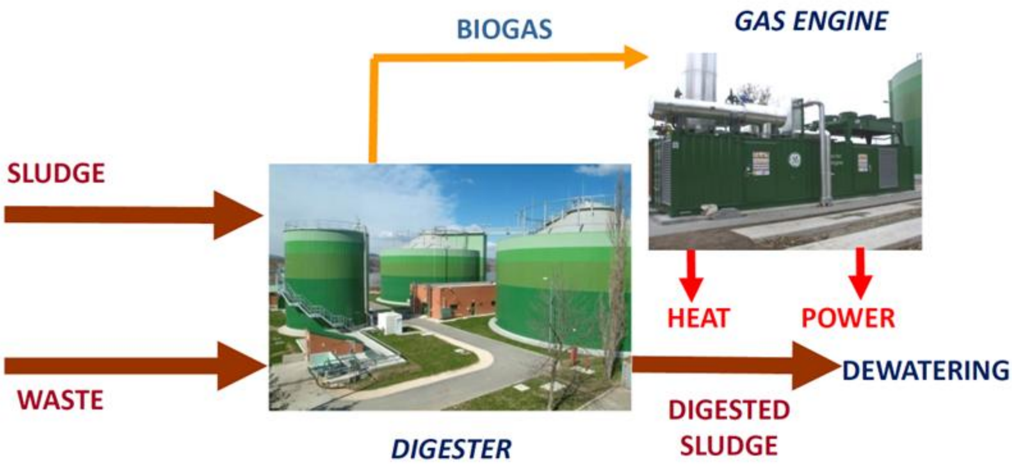
The treated biogas is stored in two double-membrane gas reservoirs, each with a capacity of 2,720 $m^3$, ensuring a reliable supply for energy generation. Excess biogas is safely flared off using gas torches with a capacity of 900 $Nm^3/h$ each, preventing unutilized methane emissions into the atmosphere.

The purified biogas is converted into usable energy through a set of high-efficiency gas engines, including one Jenbacher JMS 316 GS-B/N.LC unit and two Caterpillar G3516A units. These engines generate both electricity and heat, utilizing the plant’s biogas reserves effectively. Key highlights of energy output include:

- Electricity Production: the gas engines collectively generate electricity, significantly reducing reliance on external power sources.
- Heat Recovery: the engines recover waste heat from the combustion process, which is used for heating the digesters and other operational needs within the plant.

In 2023, the plant produced 15,025,255 kWh of electricity, only a small fraction (3,034,118 kWh) was purchased from external sources to support uninterrupted operation. The majority of the energy generated was consumed on-site, with surplus energy fed back into the grid.

The plant employs combined heat and power (CHP) units to optimize energy recovery and utilization. This approach ensures that both electrical and thermal energy produced from biogas are used efficiently. The heat generated is critical for maintaining the digesters at their optimal operating temperature of 36.5°C, supporting continuous biogas production. Additionally, thermal energy supports various auxiliary processes, reducing dependency on external heating systems.




*38. Figure: The steps of energy recovery in the North-Budapest WWTP*

The energy recovery system at the North-Budapest Wastewater Treatment Plant exemplifies sustainability. By achieving 91.9% energy self-sufficiency in 2023, the plant reduces operational costs and reliance on non-renewable energy sources. This level of efficiency also translates to significant environmental benefits, including:

- Reduced Greenhouse Gas Emissions: methane, a potent greenhouse gas, is captured and utilized rather than being released into the atmosphere.
- Lower Carbon Footprint: the use of renewable biogas for energy generation minimizes the plant's overall carbon emissions.
- Resource Efficiency: the integrated system ensures that every possible energy source within the plant is utilized effectively, contributing to the circular economy.

### The utilisation of the sludge product[44]

Stabilised, dewatered sludge is transported from the plant for further treatment and use. The overall utilisation of the product is managed by EWC-H Ltd that is a market based company specialised in waste management focusing on organic wastes (food industry, communal sludge, etc.). At the sites managed by the company, the sludge (and other organic wastes) undergo a process of stabilisation and according to their content specific agents, such as straw or similar non-hazardous materials are mixed to the sludge to achieve optimal chemical and physical state. The materials then are applied on various rehabilitation areas, such as old mines, tailings etc.; the sludge from the North-Pest WWTP is now transported to the Ajka bauxite mine tailings for further processing and the for the rehabilitation of the mining and tailing areas.

[44] The contribution of the EWC-H Ltd. is greatly appreciated; information presented in this section were provided by EWC-H Ltd.

*39. Figure: The prpocessing of sludge and other organic waste at the EWC-H plant*


*40. Figure: A former EWC-H plant near Ajka under rehabiliation*

*A part of the land of the rehabilitated site is now used for solar energy production. (Photo: GoogleMaps)*

# 7 Summary and recommendations

## 7.1 Main trends and challenges

With the development of the sewage systems and the sewage treatment technologies in the region the quantity of sludge has grown in the last two decades. It has to be noted, however, that in the last few years no significant growth in quantities has been recorded. There is a clear difference between the upstream, central and downstream countries along the Danube: in the highly developed upstream areas sewage system coverage is at reasonable level, treatment produces large quantities of sludge; in the central region waste water treatment has been developed steadily over the last decade, and sludge quantities have grown; this growth seemed to slow down in the last years. At the same time, in the downstream countries waste water treatment recently gained impetus, however steady and significant growth in sludge quantities are still not recorded. Financial feasibility related to waste water and sludge management in areas with small and scattered settlements remains an issue in the central and downstream countries.

The quality of sludge also changed in parallel to the advancement of sewage system. New materials occur in sludge in growing quantities that are those of growing concern, namely micropollutants, plastics and pharmaceuticals. These compounds are not monitored regularly and put burden on the further recovery of the various sludge products.

At the same time, many central and downstream countries of the Danube Region use treated and composted sludge in their agricultural sectors. Following the adaption of new strategies, community legislation is being revised, including waste water treatment and the use of sludge. Whereas in the middle- and lower-income countries agricultural recovery seems the more feasible solution in mid-term, the long-term shift towards other recovery techniques is receiving growing attention.

The magnitude of the new challenges is mirrored in the number of the newly published strategies and legislation and the ongoing consultation processes on new policy papers. There are a number of community level strategies and legislation that directly or indirectly relate to sludge management; many of these papers are the result of the accelerating greening of our economies and societies and are being revised according to the new challenges. Although some of the legislation in power are rather old, in the middle and downstream countries of the region actions for compliance are in progress just as in the case of non-EU countries.

The European Green Deal requires that all socio-economic process shall be altered towards sustainability; the idea is already with us for quite some time now, it’s the first time, however, when a cross-sectoral, community level policy document defines specific targets and actions for the achievement of sustainability goals.

According to the Green Deal and the Circular Economy Action Plan there are three main areas that may be of concern in the new era; a balance of feasible and non-polluting solutions is to be found, where sludge is considered

- a material to be used in agriculture to preserve and improve soil quality,
- a raw material for industrial processes, and
- an energy source.

Meanwhile the regulations on pollution are also getting stricter, the Zero Emission Action Plan, being drafted, is going to call for even stricter thresholds for soil and water usage, and also promotes the ambition for zero emission in all sectors. There is a special and growing concern about micropollutants, pharmaceuticals and microplastics; they are relatively new materials of concern, new management techniques and technologies for their management are to be developed.

The foreseen growth of quantity and the changing quality of wastewater poses a challenge on treatment technologies, their feasibility and also on institutional and technological management.

The changing situation, and all these policy developments are now mirrored in the process of the revision of the Sewage Sludge Directive. A few years ago, the revision of the directive started with the preparation of support studies for the evaluation of the directive, and the directive itself was thoroughly assessed and evaluated. This process has now ended and the development/concise revision of the new SSD directive is undergoing. The new directive is to fully consider the new market developments, new scientific findings on pollutants and new approaches of resource and energy efficiency.

All in all, the new requirements, growing quantities and worsening quality require sludge management solutions that are more and more expensive to install and their operation requires considerable resources. At the same time, these solutions can generate income that may cover considerable parts of the operation of the wastewater and sludge management systems. Investment needs, however, are rather high even in the case of the simpler technologies and considering that the provision of the higher environmental standards is possible only with the application of expensive new technologies, countries of the region with lower incomes (central and downstream countries) may face problems of financing their plans for better sludge management.

The quantity of sludge slowly increases in the upstream countries due to the increasing water use and the further development of sewerage systems. In the downstream countries, at the same time, the quantity of sludge is expected to increase somewhat faster as new sewage systems are installed in large agglomerations. Sludge management of the downstream countries is at its early phase. The growing pollution level of sludge is receiving growing attention and environmental standards are becoming stricter.

The sewage and sludge management of small settlements, especially those with scattered spatial distribution, is receiving growing attention.

Policy or legislative documents are available in a number of countries, their orientation and detailedness greatly differ.

Sludge is to be fully recovered; a balance should be found among recovery techniques focusing on utilising sludge as a raw material, an organic source for soil and energy production. Technologies complying with the latest standards are expensive therefore hardly affordable for the lower income countries of the region.

Specific, Danube Basin oriented forecasts for sludge production and planned management methods do not exist. The lack of such forecasts suggests that there is a considerable knowledge gap on the Danube Region level.

## 7.2 Possible themes of common interest

### Arising issues

As presented above, there are several changes in trends that affect all Danube Region countries. To resolve the common technological and policy problems there are a number of areas where Danube Region countries can co-operate.

One important issue is the relative underdeveloped sludge management systems of the downstream and partly central countries; due to increasing sludge quantities, the gap is expected to grow. At the same time, countries with long history in sludge management collected relevant experience already and there are good examples that may be adapted by all countries and regions or even locations at the different phases of sludge management. Thus, a collection of best practices on sludge management can be of interest of all countries in the fields of

- Available technologies in general (e.g. see German collection of good practices[45])
- The organisation of sludge management systems
- Attracting private investment in the sludge management sector
- Emerging new technologies in relation to
  - management of micropollutants
  - small scale treatment and recovery systems
  - energy recovery

In addition to general issues, countries facing similar problems, or countries with proven and well-functioning systems and countries in the earlier phases of sludge management can develop specific national or regional level partnerships on the transfer of technology and know-how.

Despite of the research efforts and extensive experience gathered, there are considerable gaps in available technologies concerning specific local situations. These specific issues cover technological issues in the handling of specific compounds, effective energy generation or specific local/microregional assets, such as transboundary situations, scattered/small settlements, etc. The themes to be further developed are:

- Research and development of techniques based on best practices – see above
- Assessment of available technologies in specific socio-economic situations – financial and environmental feasibility
- Feasibility of cross-border sludge management systems – selected locations

45 https://www.umweltbundesamt.de/sites/default/files/medien/378/publikationen/technical_guide_on_the_treatment_and_recycling_techniques_for_sludge_from_municipal_waste_water_treatment_0.pdf

- Pollutants' pathways related to sludge management and recovery – soil, groundwater and surface water contamination /
  - agricultural recovery
  - energy recovery
  - landfill pathways
  - recultivation pathways
- The specific characteristics of agricultural sludge, special treatment and recovery techniques, pathways of typical pollutants
- Monitoring systems for the tracking
  - sludge related pollutants (households / farms – sewage – sludge – soils / water – food / ecosystems)
  - recovery pathways
- Energy recovery from sludge
- etc.

Infrastructural developments are usually managed within national systems, countries develop their own sludge management related strategies and/or legislation and sludge is managed on a sub-regional or sewage agglomeration basis. Impacts of the management, however, may be transboundary in the case of surface- and groundwater or air pollution. Whereas export/import of sludge is an existing practice to better utilise national capacities and arrive to a more feasible solution, growing environmental consciousness calls for the revision of monitoring systems, and well established and transparent interregional co-operation. Still, "international" management of sludge is rare, in spite of the fact that some enterprises having well developed know-how at hand may provide sufficient service to their partners throughout the entire Danube Region. The financing of investment is also an issue in this regard as more developed technologies are expensive to install and operate, however they generate income in the operational phase. The themes for discussion in relation to the above are, for example,

- the establishment of sludge related monitoring systems (sources, pollutants and recovery),
- the promotion of common regional management systems utilising existing recovery capacities, and
- to reveal and promote financial/funding possibilities for the development of sludge management systems.

Especially concerning the recent scientific developments and policy and legislative efforts related to emerging pollutants, there is a strong need to address the issue in the contect of the work of the EUSDR as well. Thus, specific concern is to be given the emerging pollutants, such as microplastics, pharmaceuticals, residuals from the beauty industry, etc. in the framework of

- Enhancing measuring and monitoring
- Supporting research on the routes of the pollutants
- Supporting development of efficient treatment / recovery technologies

### Themes for development proposed by actors

The survey conducted during this study revealed a number of issues the professional actors of the EUSDR PA4 are interested in (see chapter 5 for details). The suggestions for the

Euregion include several themes, many of which overlap with the above ones and can be organised around the below themes:

- Support strategic decision making and finance
- Research and development on emerging contaminants
- Support awareness raising for various actors

It has to be noted that the issues raised by the PA4 actors reflect the present state of waste water and sludge management situation of the given country or region. This means that besides professional interest the existing experience, strategic and legislative background, knowledge, means of actions are different along the EUSDR; this phenomenon may have significantly impact on the possibility of common action, however, in the same time, it gives room for smoother development of the less advanced countries.

## 7.3 Pre-requisites for common thinking

There are several elements of sludge management that are not well known or defined that hinder communication especially at international level. Firstly, there are no current data available on the production and management of sludge in some countries of the Danube Region. In some countries strategies and legislations are being developed (e.g. Romania and Serbia) and/or revised and, moreover, sewage treatment has been developing fast in the downstream countries, meaning that any comprehensive report (such as the JRC report[46]) will need to be revised in a few years. Secondly, applied technologies differ in the region and their national definitions can be applied with limitations as shown in data discrepancies of the country reports and EUROSTAT data. At the same time, with the emergence of and investment in new wastewater treatment plants, new techniques and technologies, the focus and the efficiency of sludge management undergo considerable changes.

The problematics related to agricultural sludge is similar, however the data coverage of the issue is extremely weak: no specific data are available, specific practices are rarely known. The filling of the gap in our knowledge on agricultural sludge is of primary importance to improve the situation in this field.

This changing situation and the expected future trends shall be considered for any further development of sludge management at Danube Regional level; the discussion before arriving to a common understanding in the Danube Region require some information to be considered through

- definition of professional terms; glossary of commonly used terms and definitions;
- a concise and up-to-date assessment and establishment of a reporting/monitoring procedure to acquire up-to-date and well useable data;
  - of sludge management practices in the EUSDR countries / regions including investment and operational costs and benefits,

[46] https://ec.europa.eu/jrc/en/publication/eur-scientific-and-technical-research-reports/wastewater-treatment-danube-region-opportunities-and-challenges

  - sludge volumes and quality: communal and agricultural sludge,
- a detailed comparative assessment of existing strategic and legislative documents across the region with concern on the documents available only in national languages;
- forecasting sewage and sludge volumes together with estimations concerning quality issues in the case of communal and agricultural sludge,
- preparing a summary of existing sludge management strategies / plans, expected developments in sewage treatment, population and livestock;
- preliminary full list and comparative analysis of available sludge treatment and recovery techniques and ongoing research and development;
- good practices for financing sludge management.

## 7.4 Recommendations

According to the community legislation, the management of sludge is within national responsibility. Countries have developed different methods for sludge management, the new trends are, however, seen in line with the changing community strategies and recommendations and developing technologies.

The role of the EUSDR in these processes can be relevant in the support of efforts to invest in and operate sludge management systems, dissemination of know-how and promotion of good practices for the improvement of water and soil quality in the region. This assistance can consist of the establishment of efficient channels to disseminate information, know-how and best practices and to facilitate joint projects among EUSDR countries. The co-operation supported by EUSDR can be a basis of future joint action e.g. on common objectives and measures.

According to the above in the short-term the following action can be useful in the field of sludge management in the Danube Region:

- raising awareness of sludge management issues at
  - internal actors, such as national line ministries, water management bodies, including or via the Steering Group of EUSDR PA4
  - and external stakeholders, such as the EU institutions, international water management and environmental organisations,
- transferring the messages of the Danube Region countries to central European bodies acting in legislation and strategy formulation,
- supporting the launching of projects on
  - establishing a solid handbook on definitions and available sludge management techniques and systems,
  - data collection on sludge management along the region,
  - forecast of future trends concerning sludge quality and volumes,
  - formulation of a vision on sludge management that may serve as a basis for strategic thinking,
- supporting initiatives to collect and disseminate data and information on the present situation at Danube Region level,
- support efforts to forecast future trends concerning technologies, sludge quantity and quality, and
- assist in fundraising for local and regional projects through disseminate relevant information for the countries.

For short-term action in sludge management across the region, the following tools are recommended based on the priorities to be set by the participating countries:

- Facilitate discussion on sludge management issues in the EUSDR and with other stakeholders
- Initiate follow-up studies
- Organisation of forums for further discussions on sludge management
  - Organisation of special workshops / dedicated seminars for participating countries to share experience in strategy formulation, investment in and operation of sludge management systems
  - Invitation of speakers for on-line seminars on possible solutions, dissemination of best practices and know-how
- Increase visibility of the sludge issue for professionals, institutions and political decision makers at national and international level
  - Issuing statement highlighting the importance of the sludge issue
  - Organising on-line seminars and prepare on-line educational materials on possible challenges and solutions for professionals
  - Attend conferences and exhibitions related to sewage treatment and sludge management

The specific actions proposed by the stakeholders and actors, as revealed from the survey conducted, include the following:

- Development of a common, country specific sludge management strategy
- Development of common methods for the monitoring and measuring of emerging contaminants, organic matter and pathogens
- Campaigning, awareness raising and training to promote strategic and legislative developments, professional and public concern and co-operation
- Regional exchange of best practices
- Pilot projects and cross-border demonstration plants
- Assist in the absorption of financial support for projects

# Annex 1: Basic definitions[47]

## Sludge treatment

*Digestion*

Digestion is a stabilisation method for primary and secondary sludge used in order to reduce the active organic load and the quantity of sludge through biodegradation. In anaerobic digestion the biodegradation of organic material content takes place in the absence of oxigen while methane gas (biogas) is generated as a by-product which can be used in further drying of the sludge.

*Dewatering*

Sludge dewatering is an operation to increase the solid content of sludge and also remove part of the water fraction. The benefit of the technique is that the volume of sludge decreases which can decrease the necessary size and capacity of the treatment equipment.

*Drying*

Drying is a technique that reduces the bound water content of sewage sludge.

- Solar drying: drying sewage sludge using solar energy
- Direct drying: drying sewage sludge by direct heat transfer (e.g. warm air)
- Indirect drying: drying of sewage sludge by indirect heat transfer (via heat transfer surface)

*Composting*

Composting is an Aerobic (termophilic) sludge stabilization process, in which the appropriate dry matter content and C/N ratio is adjusted by adding appropriate additive and then the mixture is aerated naturally or artificially until approximately up to 70°C temperature is reached. When heavy metal concentrations and pharmaceutical residues are acceptable, sewage sludge from municipal WWTPs are generally good composting feedstock. The method is great to achieve sufficient hygienisation/stabilization. Eventhough composting is generally a good technique to treat sewage sludge, it produces significant GHG emissions and causes odour nuisances.

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[47] Technical Guide on the treatment and recycling techniques for sludge from municipal waste water treatment https://www.umweltbundesamt.de/sites/default/files/medien/378/publikationen/technical_guide_on_the_treatment_and_recycling_techniques_for_sludge_from_municipal_waste_water_treatment_0.pdfhttps://www.umweltbundesamt.de/sites/default/files/medien/378/publikationen/technical_guide_on_the_treatment_and_recycling_techniques_for_sludge_from_municipal_waste_water_treatment_0.pdf

## Sludge recovery

*Agricultural recovery*

Agricultural recovery can happen through composted sludge or artificial soil application as nutrient replenishment of the agricultural land by injection or plowing. When composted sludge is used in agriculture it is vital to ensure it is safe and stable, C/N ration must be less than 22 to be safe. The agricultural utilization of sludge must be limited to sludges with no or an acceptable low content of contaminants and a high content of available phosphate. Only sludges that are licenced should be used. EU Directive 86/278/EEC regulates how sewage sludge can be used in agriculture, while national laws and regulations are in place as well. Despite laws and regulations being in place, risks from contaminants and pathogens are not finally evaluated and cannot be eliminated entirely. All in all agricultural use of sewage sludge must be closely monitored and the legal requirements should be strictly implemented.

*Recultivation recovery*

Recultivation's basic meaning is making an area recyclable. The set of technical, biological and agronomic processes during which land that has become infertile due to harmful effects of natural or human (anthropogenic) activity (e.g. landfill, surface mine, landscape wound) becomes suitable for restoration to agricultural, forestry or other activities.

Mixtures of soil and sludge material are usually derived with anaerobically digested, lime-stabilised or composted sludge. Risks of recultivation are the same as in case of agricultural recovery, therefore thorough analyses and permits are required.

*Energy recovery*

Energy recovery is a recovery operation in which the energy content of waste is recovered, including the production of energy from biodegradable waste and the processing into a material that is used as a fuel. Energy recovery of sludge can happen through steam turbines, gas engines or pebble-heaters.

The steam turbine technique ensures a safe destruction of the organic contaminants and pathogens in the sludge. Energy potential of the sludge is exploited for power generation or to fed heat-requiring processes for sludge pre-treatment. It enables the self-supply of WWTPs with energy and heat. Thermal utilization is usually an expensive option for WWTPs due to investment costs and to higher fees that must be paid to operators.

Pyrogas obtained from sludge gasification processes can be used to power a gas engine which is coupled with a generator producing heat and power. The techniques downside is that depending on the quality and type of process employed there might be no chance for a recovery of valuable components other than the energy contents, therefore there is a loss of nutrients.

Pebble-heaters are especially suitable for small-scale incineration in combination with a micro gas turbine for producing electrical energy from the hot flue gases, without requiring the installation of a water-steam cycle. Compressed air is heated to about 900°C while passing through the pebble-heater and then applied to a turbine. This turbine drives both the compressor and the generator to produce electricity.

*Final landfilling*

Landfilling is the placement of waste on or in the surface of the geological medium – in compliance with the relevant environmental, public health and safety requirements.

The disposal of sludge on landfills should remain the last and ultimate solution for sludge amounts and residues from sludge treatment processes for which no other uses or disposal options can be found. Sludge can be mono-landfilled or co-disposed with solid household waste at sanitary landfills of appropriate standard. There are two basic types of co-disposal methods: sludge/solid waste and sludge/clay mixtures. Mixtures of the latter kind can in particular be used at operating landfills for daily coverage.

Landfilling is a comparatively low cost method at existing landfills of appropriate standard. Nonetheless it is a method that goes hand in hand with the loss of all benefits from sludge utilization, loss of the nutrients in the sludge and creation of an environmental burden.

*Phosphorus recovery*[48]

Processes for the recovery of phosphorus can be integrated at different stages of sludge treatment. Phosphorus as a scare resource is recovered for direct use as a fertilizer, thus substituting certain amounts of fertilizers from primary raw materials. Elimination of phosphorus has positive impacts on the further processing of sludge, although the processes are generally cost intensive.

A portion of the dissolved phosphorus in the waste water and the colloidal, fine particulate fraction are incorporated into the activated sludge or precipitated and removed with the excess sludge from the cleaning system. The phosphate released during the decomposition of organic substances in the digester for the most part is also bound by flocculating agents. The concentration of phosphorous in the medium to which the technical measures for its recovery will be applied is critically important to achieve a high recovery rate. In Europe only a few process operators today can assert the economic viability of the applied phosphorus recovery processes, there are many more processes however that are just at the pilot stage and have not yet achieved market maturity.

[48] A new Circular Economy Action Plan For a cleaner and more competitive Europe; Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions; COM/2020/98 final https://ec.europa.eu/environment/circular-economy/

## Annex 2: The questionnaire of the survey

## Annex 3: Survey data

Submitted electronically

Data owner: EU Strategy for the Danube Region Priority Area 4 – Water quality