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Preparatory study on sewage sludge management in the Danube Region

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Assigned by the

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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

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 some public resistance 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 the framework contract signed between the HMFAT and the KSZI-TRENECON-REKK group of consulting companies for the support of the project “Support of the capacities of applicants and beneficiaries in connection with the Danube Region Strategy and the European Grouping for Territorial Cooperation” of the Public Administration and Civil Service Development Operative Programme of Hungary (KÖFOP 3.3.3-15-2016-00002).

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 of the Protection of the Danube River and the International Sava River Basin Commission. General observations were made through the review of the documents behind the activities, notably the countries' strategies and action plans.

The second part of the study focuses on the newly emerging challenges. Lastly, the study tries to give clear indication of the possible forms and themes of common thinking on sludge management within the EUSDR.

In more details, the main areas discussed in the study are as follows:

- State-of-play, assessment of the effective EU regulations including available BREF (Best Available Techniques Reference Document) documents
- State-of-play, assessment of the current processes of sewage sludge generation, recovery and export by the countries in the Danube Region
- Identifying best practices for required measurable targets of sewage sludge treatment and recovery (from sludge to compost, sludge for energy, recovery of incineration residues) and compiling inventory of areas (compost and/or energy), instruments/facilities of required interventions.
- Best practices in relation to hazardous/non-hazardous substance content
- Willingness to recover sewage sludge – a discussion of the subject matter
- Funding issues
- Evaluation of coherence with the new EU initiatives (European Green Deal, Zero Net Emissions, circular economy etc.)
- A concise assessment of the current conditions and viability of sewage sludge recovery in the Danube Region including the discussion on the possibility of developing a consistent strategy for the Danube Region.

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[1]

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

[1] 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[2]

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[3]

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,

[2] 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/

[3] 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)

> "*An EU fertilising product may contain compost obtained through aerobic composting of exclusively one or more of the following input materials:*
>
> *…*
>
> - *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[4]

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.

[4] 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

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[5]

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.

EU Biodiversity Strategy for 2030[6]

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.

[5] 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

[6] 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

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[7]

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

Thematic Strategy for Soil Protection COM(2006)231[8]

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

[7] 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

[8] 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

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[9]

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 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[10]

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.

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[9] 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

[10] 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

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[11]

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.

General Union Environmental Action Programme to 2030 (8th Environmental Action Programme)[12]

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

[11] 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

[12] 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

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[13]

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.

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.

[13] 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/

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 Sludge treatment in the Danube Region countries – an overview

3.1 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/web/products-datasets/product?code=env_ww_spd in the end of October, 2020, containing data from 2018; note that in the case of some countries data from 2016 were made available in the dataset; in the figures the most recent data is presented as shown in the supporting tables. In the figures and tables, the terminology of EUROSTAT is used. 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 unproper 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.

3.1.1 Austria

National strategies and legislative background

The information used in this study came from three main sources, firstly from Austria's Biowaste Strategy (2014), secondly from a study completed by the Austrian Research Centre Seibersdorf (1997) regarding sewage sludge disposal in Austria, thirdly from Annex III of the 10th technical assessment on the Urban Waste Water Treatment Directive (UWWTD) implementation 2016 review. No specific strategies were found regarding sewage sludge treatment in Austria.

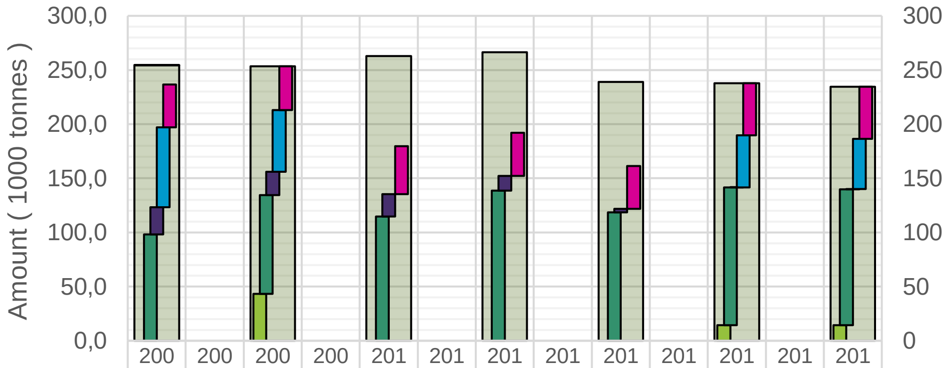
The Biowaste Strategy discusses the sewage sludge regulations of the federal states at length, mainly focusing on agricultural use. Each federal state regulates individually the extent to which sewage sludge can be applied on soil and the prohibited outputs ensuring soil protection. Amounts of phosphorus are to be monitored in sludge especially if the sewage sludge is a product of a treatment plant without phosphorus removal as the it can cause various problems in water bodies (e.g. eutrophication) if not removed.

Main figures: treatment and sludge sewage[14]

In 2016, 635 agglomerations each generated more than 2000 population equivalent (p.e) of wastewater, all of which were treated by the 635 urban wastewater treatment plants. Only 3 of the treatment plants are not capable of more stringent treatment technology than secondary.

In the same year, Austria produced 237 938 tonnes of sewage sludge. Two forms of sludge treatment techniques are used, extended sludge stabilization and simultaneous aerobic stabilization accompanied by phosphorus removal.

All in all, the country supports direct use or composting in spite of incineration, because nitrogen is released into the air during incineration and phosphorus remains unusable in the ash. Despite all the above, incineration was still the most common form of use in 2016, 53% of the treated sewage sludge was incinerated followed by agricultural recovery and recultivation.



Source: EUROSTAT

	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Produced-disposed gap*	0,3		0,0		0,0		0,0		0,0		0,0		0,0
Disposal total	254,3		253,5		262,8		266,3		239,0		237,9		234,5
1. agricultural use	39,5		40,4		44,4		39,9		39,6		48,3		48,2
2. compost and other appl.	74,0		57,2								47,9		46,3
3. landfill	24,9		21,3		20,8		13,6		3,2		0,1		0,3
4. incineration	98,3		91,4		114,6		138,6		118,5		127,2		125,4
5. other			43,2								14,4		14,4

1. Figure: Sewage sludge production and disposal in Austria

**export/import or unknown: Gap between the amounts of "Production total" and "Disposal total" calculated on the bases of EUROSTAT data is zero, because the quantities are equal.*

[14] Austria's Biowaste strategy (2014), Sewage Sludge Disposal in Austria; Austrian Research Centre Seibersdorf (1997); Annex III of the 10th technical assessment on the Urban Waste Water Treatment Directive (UWWTD) implementation 2016 review

Austria	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Production total (EUROSTAT)	**255**	**0**	**254**	**0**	**263**	**0**	**266**	**0**	**239**	**0**	**238**	**0**	**234**
Disposal total (EUROSTAT)	254	0	254	0	263	0	266	0	239	0	238	0	234
Produced-disposed gap (calc.)	0	0	0	0	0	0	0	0	0	0	0	0	0

1. Table: Calculation of “Produced-disposed gap”, Austria, thousand tonnes

The data in percentage are shown in the next table.

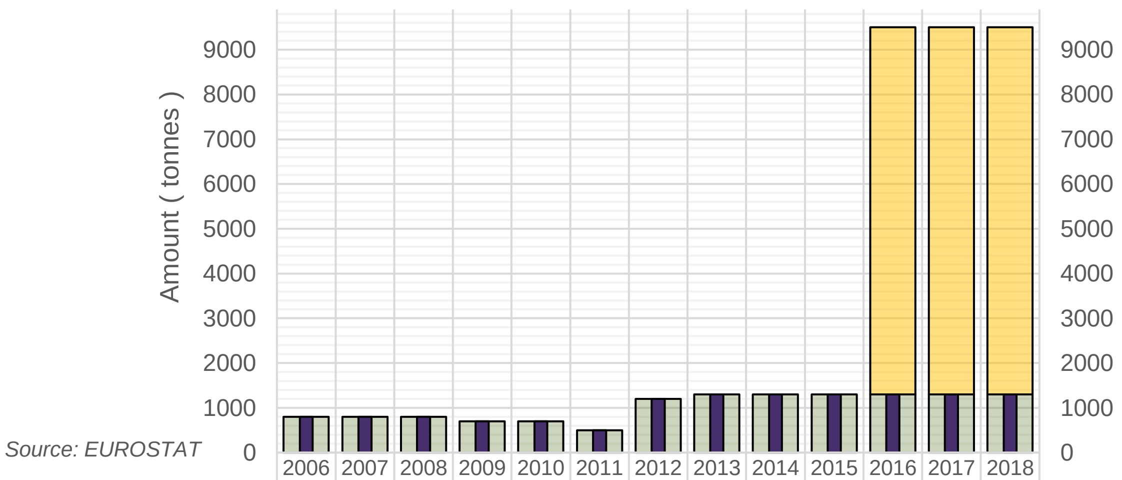
Austria	2006	2008	2010	2012	2014	2016	2018	Multi-year AVG
1. agricultural use	*16%*	*16%*	*17%*	*15%*	*17%*	*20%*	*21%*	*17%*
2. compost and other appl.	*29%*	*23%*	*–*	*–*	*–*	*21%*	*20%*	*23%*
3. landfill	*10%*	*8%*	*8%*	*5%*	*1%*	*0%*	*0%*	*5%*
4. incineration	*39%*	*36%*	*44%*	*52%*	*50%*	*53%*	*53%*	*47%*
5. other	*–*	*17%*	*–*	*–*	*–*	*6%*	*6%*	*10%*
Disposal total	100%	100%	100%	100%	100%	100%	100%	100%
Produced-disposed gap	0%	–	–	–	–	–	–	0%
Production TOTAL	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**

2. Table: Sewage sludge production and disposal in Austria, (%)

**percentages do not add up to 100% due to lack of EUROSTAT data regarding the specific disposal method*

3.1.2 Bosnia and Herzegovina

According to EUROSTAT data there was no significant amount of sludge produced in Bosnia and Herzegovina until 2015. Then wastewater treatment plants were built that resulted in growing quantities of sludge. Since then 9-10 thousand tonnes of sludge have been produced every year. Data shows that a significant amount of sludge is not being disposed.



	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Produced-disposed gap*	0	0	0	0	0	0	0	0	0	0	8200	8200	8200
Disposal total	800	800	800	700	700	500	1200	1300	1300	1300	1300	1300	1300
1. agricultural use	0	0	0	0	0	0	0	0	0	0	0	0	0
2. compost & other appl.	0	0	0	0	0	0	0	0	0	0	0	0	0
3. landfill	800	800	800	700	700	500	1200	1300	1300	1300	1300	1300	1300
4. incineration	0	0	0	0	0	0	0	0	0	0	0	0	0
5. other	0	0	0	0	0	0	0	0	0	0	0	0	0

2. Figure: Sewage sludge production and disposal in Bosnia and Herzegovina

**export/import or unknown. Data shows considerable gap between the amounts "Production total" and "Disposal total" calculated on the bases of EUROSTAT data. EUROSTAT data is not available on the difference between the two figures; 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.*

"Production TOTAL", "Disposal total" EUROSTAT data and the calculation of "Produced-disposed gap" presented in table below, where the applied formula was Gap = Production total – Disposal total.

Bosnia and Herzegovina	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Production total (EUROSTAT)	**800**	**800**	**800**	**700**	**700**	**500**	**1200**	**1300**	**1300**	**1300**	**9500**	**9500**	**9500**
Disposal total (EUROSTAT)	800	800	800	700	700	500	1200	1300	1300	1300	1300	1300	1300
Produced-disposed gap (calc.)	0	0	0	0	0	0	0	0	0	0	8200	8200	8200

3. Table: Calculation of "Produced-disposed gap", Bosnia and Herzegovina, thousand tonnes

The data in percentage are shown in the next table.

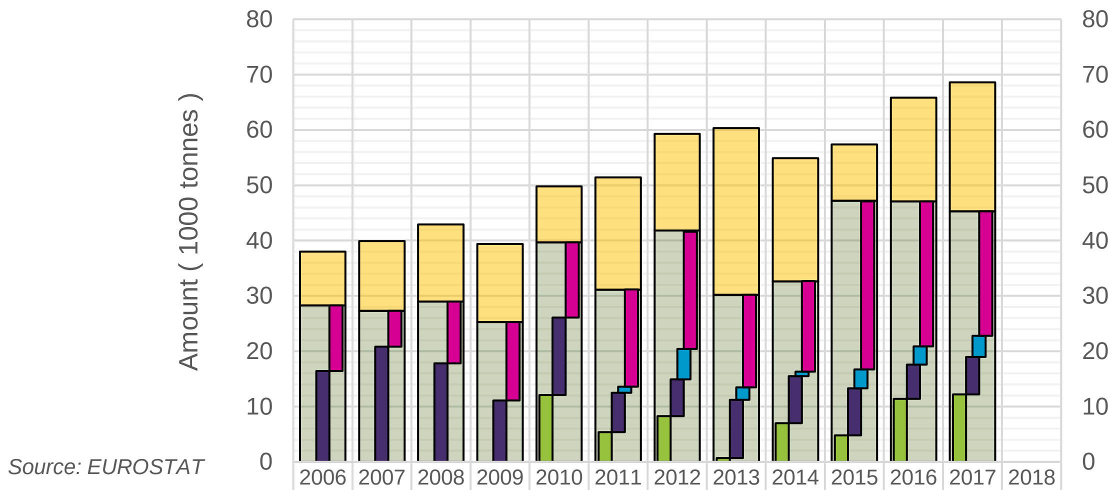
Bosnia and Herzegovina	2006-2015	2016-2018	Multi-year AVG
1. agricultural use	–	–	**–**
2. compost and other appl.	–	–	**–**
3. landfill	*100%*	*14%*	***35%***
4. incineration	–	–	**–**
5. other	–	–	**–**
Disposal total	100%	14%	**35%**
Produced-disposed gap	–	86%	**65%**
Production TOTAL	**100%**	**100%**	**100%**

4. Table: Sewage sludge production and disposal in Bosnia and Herzegovina, (%)

3.1.3 Bulgaria

According to the National chapters of the 2016 UWWTD Bulgaria is yet to meet the target for collection and treatment of wastewater. Only 48% of the generated wastewater is collected through collection systems and 147 of all 328 agglomerations don't have a treatment plants in place. The collected wastewater is treated in 255 municipal wastewater treatment plants.

In 2016 Bulgaria reported to have reused or disposed of 66, 920 tonnes of sewage sludge. EUROSTAT data showed only 65.8 thousand tonnes of sludge produced and 47.1 thousand tonnes of sludge disposed in the same year. Sewage sludge is mostly used in agriculture (30%), considerable amounts are landfilled and minor amounts are used for composting; other applications also make up a considerable part of the total sludge treated.



	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Produced-disposed gap*	10	13	14	14	10	20	18	30	22	10	19	23	
Disposal total	28	27	29	25	40	31	42	30	33	47	47	45	
1. agricultural use	12	7	11	14	14	18	21	17	16	30	26	23	
2. compost and other appl.	0	0	0	0	0	1	6	2	1	3	3	4	
3. landfill	16	21	18	11	14	7	7	11	9	9	6	7	
4. incineration	0	0	0	0	0	0	0	0	0	0	0	0	
5. other	0	0	0	0	12	5	8	1	7	5	11	12	

3. Figure: Sewage sludge production and disposal in Bulgaria

**export/import or unknown. Data shows considerable gap between the amounts "Production total" and "Disposal total" calculated on the bases of EUROSTAT data. EUROSTAT data is not available on the difference between the two figures; 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.*

“Production TOTAL”, “Disposal total” EUROSTAT data and the calculation of “Produced-disposed gap” presented in table below, where the applied formula was Gap = Production total – Disposal total.

Bulgaria	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Production total (EUROSTAT)	**38**	**39,9**	**42,9**	**39,4**	**49,8**	**51,4**	**59,3**	**60,3**	**54,9**	**57,4**	**65,8**	**68,6**	**0**
Disposal total (EUROSTAT)	28,3	27,3	29	25,3	39,7	31,1	41,8	30,2	32,6	47,2	47,1	45,3	0
Produced-disposed gap (calc.)	9,7	12,6	13,9	14,1	10,1	20,3	17,5	30,1	22,3	10,2	18,7	23,3	0

5. Table: Calculation of “Produced-disposed gap”, Bulgaria, thousand tonnes

The data in percentage are shown in the next table.

Bulgaria	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	Multi-year AVG
1. agricultural use	*16%*	*26%*	*36%*	*27%*	*34%*	*36%*	*28%*	*30%*	*53%*	*40%*	*33%*	***33%***
2. compost and other appl.	–	–	–	–	*2%*	*9%*	*4%*	*1%*	*6%*	*5%*	*6%*	***3%***
3. landfill	*52%*	*41%*	*28%*	*28%*	*14%*	*11%*	*17%*	*15%*	*15%*	*9%*	*10%*	***21%***
4. incineration	–	–	–	–	–	–	–	–	–	–	–	**–**
5. other	–	–	–	*24%*	*11%*	*14%*	*1%*	*13%*	*8%*	*17%*	*18%*	***10%***
Disposal total	68%	67%	64%	79%	61%	70%	50%	59%	82%	71%	67%	**67%**
Produced-disposed gap	32%	33%	36%	21%	39%	30%	50%	41%	18%	29%	33%	**33%**

Bulgaria	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	Multi-year AVG
Production TOTAL	**100 %**	**100 %**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**

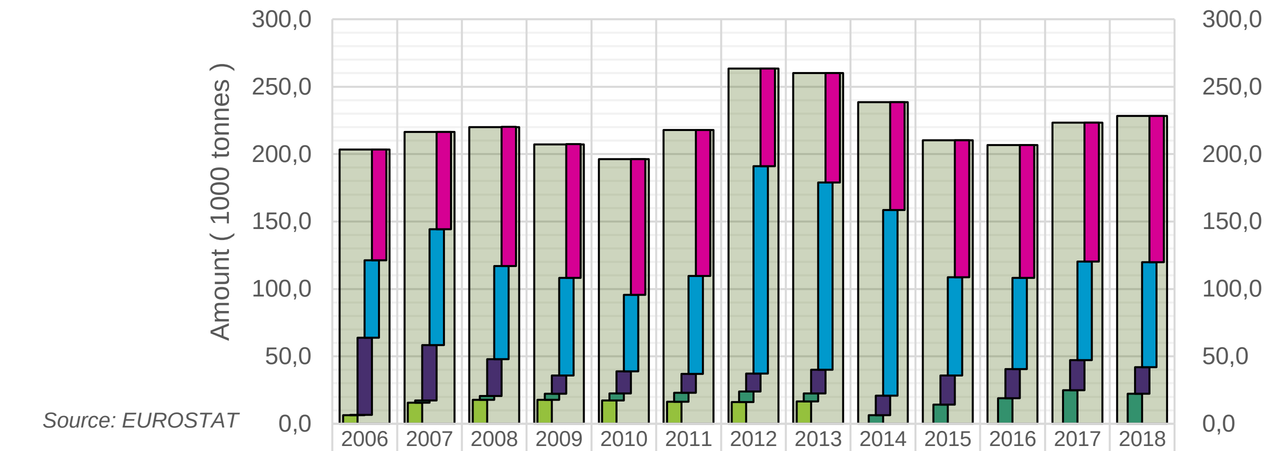
6. Table: Sewage sludge production and disposal in Bulgaria, (%)

3.1.4 Czech Republic

In 2016 in the Czech Republic 100% of the waste water load generated was collected by appropriate systems and treated by the 634 urban waste water treatment plants. In the same year 206 714 tonnes of sewage sludge was produced.

According to a 2015 study on optimization of municipal sludge management in wastewater treatment plants in the Czech Republic, sludge treatment involves the thickening of the primary and waste sludge followed by anaerob stabilisation on 37 or 55°C. Biogas generated along the process is used for producing heat and electricity as biogas is becoming increasingly valuable on the market. Sludge is also used for energy production, in this case sludge is composted or dried and used in waste incinerators as auxiliary fuel or coal power plants. The recovery of organic matter (N, P) from sludge is starting to appear as a new field as well. 42% of the generated sludge was used in agriculture, 39% was used in recultivation of old landfills and mines. 10% of the sludge was disposed off at landfills, however this amount is decreasing over the years while energy production use such as composting and incineration are increasing.

2016 and 2017 UWWTD and EUROSTAT data shows a different trend in the disposal of sludge. Only 48% of sludge is used in agriculture, 33% is reused in a different field, 10 % is disposed of at landfill and 9% is incinerated. The volume of sludge produced is decreasing since 2014 as well as disposing at landfill, while the percentage of recycling has increased significantly.



	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Produced-disposed gap*	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Disposal total	203,4	216,3	220,0	207,2	196,3	217,9	263,3	260,1	238,6	210,2	206,7	223,3	228,2
1. agricultural use	82,1	72,0	103,1	99,0	100,6	108,3	72,3	81,1	80,0	101,6	98,5	102,9	108,3
2. compost and other appl.	57,5	86,0	69,1	72,6	56,9	72,5	153,7	138,9	137,8	72,9	67,7	73,1	78,0
3. landfill	57,2	41,0	27,3	13,4	16,3	14,0	13,4	17,7	14,4	21,5	21,6	22,3	19,6
4. incineration	0,3	1,7	2,8	4,6	5,1	6,7	7,7	5,9	6,4	14,2	18,9	25,0	22,3
5. other	6,3	15,6	17,8	17,7	17,4	16,4	16,2	16,5					

4. Figure: Sewage sludge production and disposal in the Czech Republic

**export/import or unknown: Gap between the amounts of "Production total" and "Disposal total" calculated on the bases of EUROSTAT data is zero, because the quantities are equal.*

Czech Republic	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Production total (EUROSTAT)	**203**	**216**	**220**	**207**	**196**	**218**	**263**	**260**	**239**	**210**	**207**	**223**	**228**
Disposal total (EUROSTAT)	203	216	220	207	196	218	263	260	239	210	207	223	228
Produced-disposed gap (calc.)	0	0	0	0	0	0	0	0	0	0	0	0	0

7. Table: Calculation of "Produced-disposed gap", Czech Republic, thousand tonnes

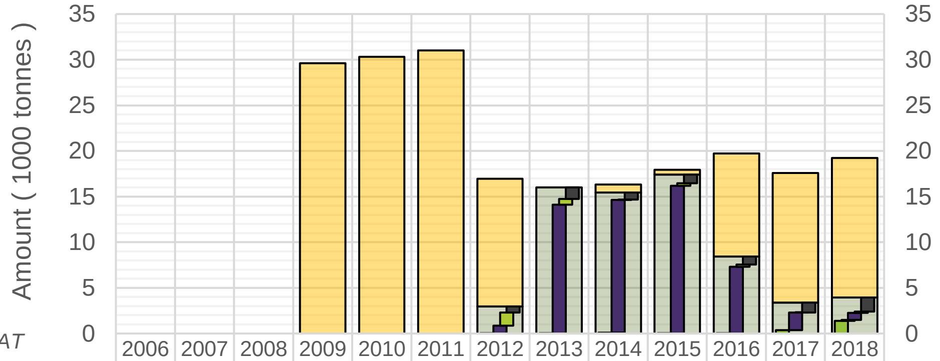
The data of years 2010-2018 in percentage are shown in the next table.

Czech Republic	2010	2011	2012	2013	2014	2015	2016	2017	2018	Multi-year AVG
1. agricultural use	*51%*	*50%*	*28%*	*31%*	*34%*	*48%*	*48%*	*46%*	*47%*	*42%*
2. compost and other appl.	*29%*	*33%*	*58%*	*53%*	*58%*	*35%*	*33%*	*33%*	*34%*	*39%*
3. landfill	*8%*	*6%*	*5%*	*7%*	*6%*	*10%*	*10%*	*10%*	*9%*	*10%*
4. incineration	*3%*	*3%*	*3%*	*2%*	*2%*	*7%*	*9%*	*11%*	*10%*	*4%*
5. other	*9%*	*8%*	*6%*	*7%*	–	–	–	–	–	*5%*
Disposal total	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Produced-disposed gap	–	–	–	–	–	–	–	–	–	–
Production TOTAL	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**

8. Table: Sewage sludge production and disposal in the Czech Republic, (%)

3.1.5 Croatia

The generated wastewater is treated in 91 wastewater treatment plants, only 7 of which are capable of more stringent treatment than secondary. According to the 2016 UWWTD report's national chapter, no data was reported by Croatia regarding sewage sludge. Data published by EUROSTATA starting from 2013 shows that the main disposal technique was landfilling. The amount disposed is still fluctuating in the country.



	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Produced-disposed gap*	0	0	0	30	30	31	14	0	1	1	11	14	15
Disposal total							3	16	15	17	8	3	4
1. agricultural use							1	1	1	1	1	1	2
2. compost and other appl.							1	1	0	0	0	0	0
3. landfill							1	14	15	16	7	2	1
4. incineration							0	0	0	0	0	0	0
5. other	0	0	0	0			0	0	0	0	0	0	1

5. Figure: Sewage sludge production and disposal in Croatia

**export/import or unknown. Data shows considerable gap between the amounts "Production total" and "Disposal total" calculated on the bases of EUROSTAT data. EUROSTAT data is not available on the difference between the two figures; 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.*

Croatia	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Production total EUROSTAT)	**0**	**0**	**0**	**29,6**	**30,3**	**31**	**16,95**	**16,02**	**16,31**	**17,94**	**19,72**	**17,6**	**19,23**
Disposal total (EUROSTAT)	0	0	0	0	0	0	2,964	16,02	15,44	17,41	8,428	3,368	3,954
Produced-disposed gap (calc.)	0	0	0	29,6	30,3	31	13,99	0	0,871	0,524	11,29	14,23	15,28

9. Table: Calculation of "Produced-disposed gap", Croatia, thousand tonnes

The data of years 2010-2018 in percentage are shown in the next table.

Croatia	2010	2011	2012	2013	2014	2015	2016	2017	2018	Multi-year AVG
1. agricultural use	–	–	*4%*	*8%*	*5%*	*5%*	*4%*	*6%*	*10%*	*5%*
2. compost and other appl.	–	–	*9%*	*4%*	*0%*	*2%*	*2%*	*0%*	*0%*	*2%*
3. landfill	–	–	*4%*	*88%*	*89%*	*90%*	*37%*	*11%*	*4%*	*37%*
4. incineration	–	–	–	–	–	–	–	–	*0%*	*0%*
5. other	–	–	*0%*	*0%*	*1%*	*0%*	*0%*	*2%*	*7%*	*1%*
Disposal total	–	–	17%	100%	95%	97%	43%	19%	21%	45%
Produced-disposed gap	100%	100%	83%	–	5%	3%	57%	81%	79%	53%
Production TOTAL	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**

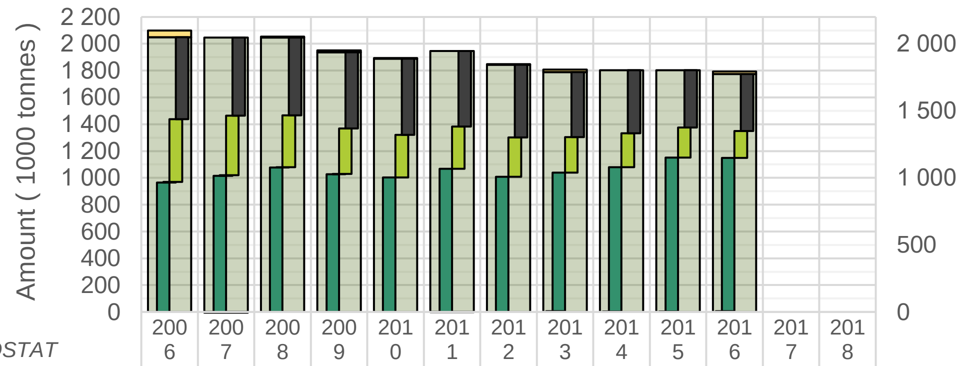
10. Table: Sewage sludge production and disposal in Croatia (%)

3.1.6 Germany

In 2016 all the generated wastewater was appropriately collected and treated in the country's 3811 wastewater treatment plants. 98% of wastewater is collected through collection systems, only 2% is collected individually or by other appropriate methods. Most wastewater is generated in Berlin, but every city has proper collection and treatment solutions.

According to Germany's sewage sludge management strategy the sewage sludge generated is treated by thickening and elimination of pathogens and pollutants followed by biological, chemical or physical sludge stabilisation. The sludge is dewatered, then most commonly dried on the sun due to the reduction of volume, the sludge is easier to store and transport, it is more microbiologically stable and safe, therefore easier to handle and increased in heating value.

Dried sludge is mainly used for energy and heat production through mono- or co-incineration. When co-incinerated, sludge is added to coal, waste or cement. In addition, large amounts of phosphorus can be recovered from sewage sludge, which can be used for several purposes, including fertilization. Germany exports fertilizers made by the recovered phosphorous to other countries as well.



Source: EUROSTAT

	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Produced-disposed gap*	51	-6	6	12	4	0	5	21	0	0	21	0	0
Disposal total	2 049	2 046	2 047	1 938	1 889	1 947	1 844	1 788	1 803	1 803	1 773		
1. agricultural use	612	582	581	570	568	564	542	484	471	428	423		
2. compost and other appl.	467	444	386	338	317	316	294	264	252	224	201		
3. landfill	5	4	3	1	0	0	0	0	0	0	0		
4. incineration	965	1 015	1 078	1 028	1 004	1 067	1 009	1 035	1 078	1 149	1 143		
5. other	0	0	0	0	0	0	0	4	3	3	6		

6. Figure: Sewage sludge production and disposal in Germany[15]

**export/import or unknown: Gap between the amounts of "Production total" and "Disposal total" calculated on the bases of EUROSTAT data is zero, because the quantities are equal.*

[15] Note that Germany is one of the largest sludge importer in Europe.

Germany	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Production total (EUROSTAT)	**2100**	**2040**	**2053**	**1950**	**1894**	**1946**	**1849**	**1809**	**1803**	**1803**	**1794**	**0**	**0**
Disposal total (EUROSTAT)	2049	2046	2047	1938	1889	1947	1844	1788	1803	1803	1773	0	0
Produced-disposed gap (calc.)	51,4	-5,7	5,7	12,2	4,414	-0,36	4,543	20,78	0	0	21,26	0	0

11. Table: Calculation of "Produced-disposed gap", Germany, thousand tonnes

The data of years 2010-2018 in percentage are shown in the next table.

Germany	2010	2011	2012	2013	2014	2015	2016	2017	2018	Multi-year AVG
1. agricultural use	*30%*	*29%*	*29%*	*27%*	*26%*	*24%*	*24%*	-	-	*28%*
2. compost and other appl.	*17%*	*16%*	*16%*	*15%*	*14%*	*12%*	*11%*	-	-	*17%*
3. landfill	–	–	–	–	–	–	–	-	-	*0%*
4. incineration	*53%*	*55%*	*55%*	*57%*	*60%*	*64%*	*64%*	-	-	*55%*
5. other	–	–	–	*0%*	*0%*	*0%*	*0%*	-	-	*0%*
Disposal total	100%	100%	100%	99%	100%	100%	99%	-	-	99,97 %
Produced-disposed gap	0%	0%	0%	1%	0%	0%	1%	-	-	0%
Production TOTAL	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**-**	**-**	**100%**

12. Table: Sewage sludge production and disposal in Germany (%)

Data from two federal states of Germany, Baden-Württemberg and Bavaria were also separately examined as they are the ones that belong to the Danube Region[16]. In 2016 Baden-Württemberg disposed of approximately 224 thousand tons of sewage sludge dry mass (t TDM) 80% of which was disposed of by incineration. Sewage sludge is also used for farming, landscaping.

In 2018, around 2600 municipal wastewater treatment plants in Bavaria produced 290 thousand tonnes of dry mass. Most of the sludge (almost 80%) was incinerated 12,5% was used for recultivation and other purposes and only 9% was used in agriculture. Thermal treatment (incineration) or energy recovery of sludge has increased from 51,7% in 2008 to 78,5% in 2018 while utilisation for agricultural and landscaping use has decreased significantly because of the potential impacts of organic pollutants from wastewater treatment such as flame retardants, disinfectants and pharmaceuticals. Landfilling has not played a role for many years as it is not permitted.

[16] https://www.stmuv.bayern.de/themen/abfallwirtschaft/klaerschlamm/index.htm
Umwelt Bundesamt: Sewage treatment in Germany; https://www.umweltbundesamt.de/en/publikationen/sewage-sludge-management-in-germany
Umwelt Bundesamt (2018): Klärschlammentsorgung in der Bundesrepublik Deutschland https://www.umweltbundesamt.de/sites/default/files/medien/376/publikationen/2018_10_08_uba_fb_klaerschlamm_bf_low.pdf

Federal state	Total disposal (t TDM)	Used for farming (t TDM)	Used for landscaping (t TDM)	Other of material recovery/ reuse (t TDM)	Thermal disposal (t TDM)	Other direct disposal
Baden-Württemberg	223,523	2,032	6,206	36	211,452	3,797
Bavaria	290,306	41,387	53,167	1,136	194,304	312

13. Table: Sewage sludge production and disposal in Baden-Württemberg and Bavaria[15]

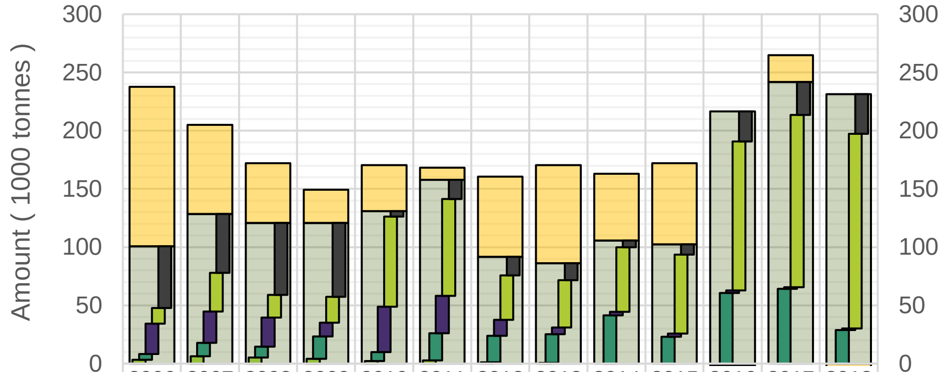
3.1.7 Hungary

In 2013 Hungary's Sludge Treatment and Recovery Strategy was completed for the 2014-2023 period. The Strategy involves situation analysis and assessment of sludge management in Hungary, as well as details on the actions to be taken and the specifics on implementation. The amount of generated sludge is expected to increase significantly throughout the examined period and is expected to reach the amount of 250 390 t_{dm}/year for 2027. 49 pilot technologies were investigated during the analyses for the strategy from the viewpoint of social benefit, findings showed that the specific net benefit typically grows with capacity increase and that composting and agricultural use is more favourable than energy recovery.

The strategy defined six main targets for the 2014-2020 budgetary cycle. First, to reach the sludge management level, which is in harmony with the recoveries, to apply more up-to date technologies in the pilot project, and then in a broader circle. Second, to increase the efficiency of sludge treatment through regional organizations. Third, to maintain the agricultural use at level, to increase it, to increase its efficiency. Fourth, to increase the efficiency of recultivation recovery, to introduce strategy level planning in using the recultivation areas, providing efficiency thereby. Fifth, to increase the ratio of energy recovery, establishing the capacities for energy recovery, to build it gradually. Finally, to handle the regulatory institutional and financing deficiencies with management tools.

For agricultural recovery the focus of the strategy is the safe re-use of substances with high phosphorus content so that the waste could turn to marketable product and at the same time viewing sewage sludge as a renewable energy source, representing new perspective for its recovery opportunities as well. EUROSTAT data shows that the most common way of sludge recovery was composting and recultivational use in the past few years followed by agricultural use and incineration while landfilling has gradually decreased during the examined years.

Data also shows that in some years the amount of total sludge disposal exceeds the amount of sludge produced in the same year. The reason is that Hungary had been importing and treating sewage sludge from other countries which is no longer an option due to change of legislation.



Source: EUROSTAT

	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Produced-disposed gap*	137	77	52	29	39	11	69	84	57	70	-2	23	-14
Disposal total	101	128	121	121	131	158	92	86	106	102	217	242	231
1. agricultural use	53	50	62	63	5	16	16	15	6	9	26	28	34
2. compost and other appl.	13	33	20	22	77	83	38	41	55	68	128	148	167
3. landfill	26	27	25	12	39	32	14	6	3	3	2	1	2
4. incineration	5	12	9	19	8	23	23	25	41	23	61	64	29
5. other	3	6	5	4	2	3	1	1	0	0	0	0	0

Figure 7: Sewage sludge production and disposal in Hungary

**export/import or unknown. Data shows considerable gap between the amounts "Production total" and "Disposal total" calculated on the bases of EUROSTAT data. EUROSTAT data is not available on the difference between the two figures; 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.*

Hungary	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Production total (EUROSTAT)	**237,6**	**205**	**172,2**	**149,3**	**170,3**	**168,3**	**160,6**	**170,5**	**163,1**	**172**	**215,1**	**264,7**	**217,8**
Disposal total (EUROSTAT)	100,6	128,3	120,7	120,7	131	157,8	91,63	86,21	105,7	102,5	216,6	241,8	231,3
Produced-disposed gap (calc.)	137	76,7	51,5	28,6	39,39	10,54	68,97	84,26	57,39	69,52	-1,51	22,96	-13,5

14. Table: Calculation of "Produced-disposed gap", Hungary, thousand tonnes

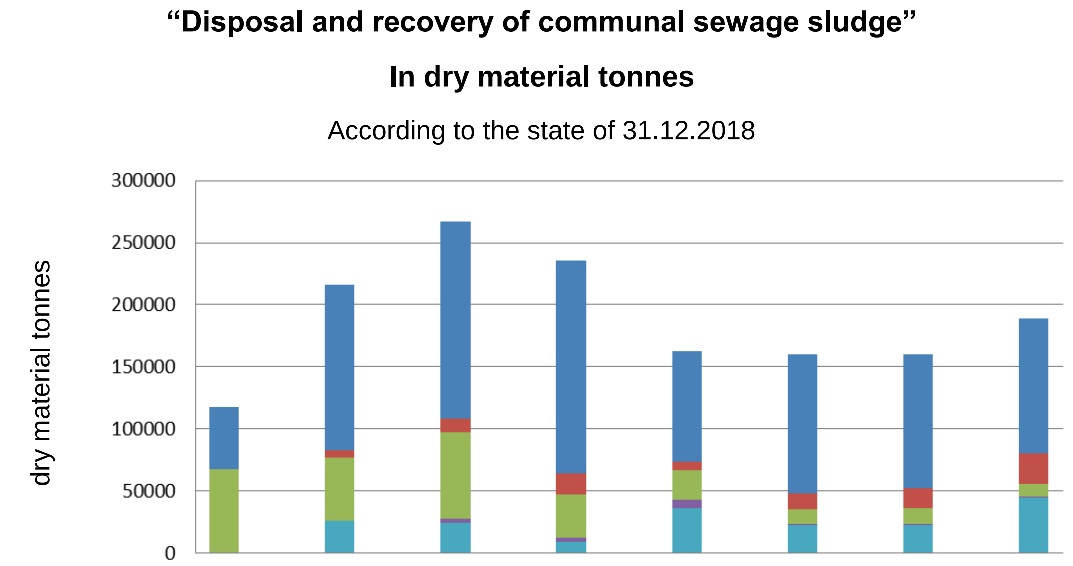
The data of years 2010-2018 in percentage are shown in the next table.

Hungary	2010	2011	2012	2013	2014	2015	2016	2017	2018	Multi-year AVG
1. agricultural use	*3%*	*10%*	*10%*	*9%*	*4%*	*5%*	*13%*	*11%*	*16%*	*16%*
2. compost and other appl.	*45%*	*49%*	*24%*	*24%*	*34%*	*40%*	*59%*	*56%*	*77%*	*36%*
3. landfill	*23%*	*19%*	*9%*	*3%*	*2%*	*2%*	*1%*	*0%*	*1%*	*8%*
4. incineration	*4%*	*14%*	*13%*	*15%*	*25%*	*13%*	*28%*	*24%*	*12%*	*14%*
5. other	*2%*	*2%*	*1%*	*0%*	–	–	–	–	–	*0%*
Disposal total	77%	94%	57%	51%	65%	60%	101%	91%	106%	74%
Produced-disposed gap	23%	6%	43%	49%	35%	40%	-1%	9%	-6%	26%
Production TOTAL	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**

15. Table: Sewage sludge production and disposal in Hungary (%)

Besides the above presented data reported to the EIROSTAT, the Department of Hydrography and Water Basin Management of the General Directorate of Water

Management of Hungary provided additional data on sewage management as shown below:



	2004.12.31	2006.12.31	2008.12.31	2010.12.31	2012.12.31	2014.12.31	2016.12.31	2018.12.31
Soil/agricultural	50 608	133 416	158 666	172 118	89 720	111 750	108 008	108 649
Other recovery	0	6 385	11 136	16 553	6 891	12 479	15 993	25 385
Disposal / landfill	67 085	50 479	69 134	35 294	23 893	12 325	12 378	10 157
Incineration	0	0	3 873	2 837	6 699	864	861	199
Other disposal	0	26 148	23 849	9 241	35 810	22 327	22 737	44 897

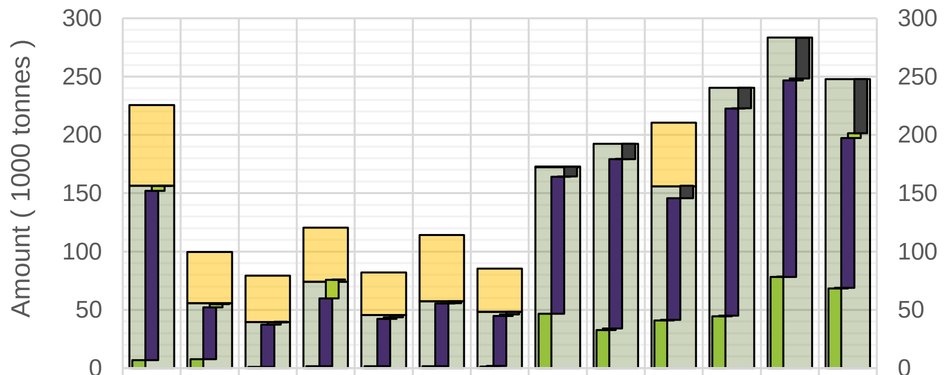
Figure 8: Sewage sludge disposal in Hungary; data of the General Directorate of Water Management

When figures 7. and 8. are compared, some data discrepancies are clearly visible: whereas the amount of sludge recovered decreased in the period of 2006-2008, data from the Water Directorate shows considerable growth. In general, it can be seen that agriculture is the dominant user of sludge and alternative ways of recovery and disposal are gaining higher importance in the last years.

Whereas some differences between the two datasets can be attributed to, for example, the different calculation methods of the amounts, the phenomenon of different trends indicated that there are / had been some gaps in the management or the reporting of the data from different sources. The Authority in its comment also pointed out that there are considerable differences between the data provided by treatment plants and authorisations issues by the National Authority for Food-chain Safety concerning agricultural use. So that, the Authority agrees with the statement made above (see the "EUROTAT" table) that "*Data shows considerable gap between the amounts "Production total" and "Disposal total" calculated on the bases of EUROSTAT data. EUROSTAT data is not available on the difference between the two figures; 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"* and also would point out the existence of a data gap in regards sewage sludge recovery and disposal.

3.1.8 Romania

According to EUROSTAT data sludge quantities started to significantly increase in Romania in 2013, due to accelerated efforts in the development of waste water treatment. Since then, every year, except for 2015, all of the produced sludge was disposed off. The main disposal technique is landfilling, while from 2013 the agricultural use of sludge is increasing. Other techniques of disposal (such as energy production, phosphorous recovery, soil quality improvement) are present as well although no sufficient information has been found on these.



Source: EUROSTAT

	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Produced-disposed gap*	69	44	40	47	37	57	37	0	0	55	0	0	0
Disposal total	156	56	40	74	46	57	48	172	192	156	240	283	248
1. agricultural use	0	1	1	0	2	2	2	8	13	11	18	35	46
2. compost and other appl.	4	3	2	16	1	0	1	0	0		0	2	4
3. landfill	145	44	36	58	41	54	43	118	145	104	178	168	128
4. incineration				0	0	0	0		1	1	0	0	1
5. other	7	8	1	2	2	2	1	47	33	41	44	78	68

9. Figure: Sewage sludge production and disposal in Romania

**export/import or unknown. Data shows considerable gap between the amounts "Production total" and "Disposal total" calculated on the bases of EUROSTAT data. EUROSTAT data is not available on the difference between the two figures; it concluded during the national revision of the data, the data collection process was incomplete. (Export-import was not recorded in Romania.)*

Romania	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Production total (EUROSTAT)	**225,6**	**99,6**	**79,2**	**120,5**	**82,1**	**114,1**	**85,4**	**172,8**	**192,3**	**210,5**	**240,4**	**283,3**	**247,8**
Disposal total (EUROSTAT)	156,4	55,6	39,6	74	45,5	57,4	48,4	172,4	192,3	155,8	240,4	283,3	247,8
Produced-disposed gap (calc.)	69,2	44	39,6	46,5	36,6	56,7	37	0,4	0	54,64	0	0	0

16. Table: Calculation of "Produced-disposed gap", Romania, thousand tonnes

The data of years 2010-2018 in percentage are shown in the next table.

Romania	2010	2011	2012	2013	2014	2015	2016	2017	2018	Multi-year AVG
1. agricultural use	*2%*	*2%*	*3%*	*5%*	*7%*	*5%*	*7%*	*12%*	*19%*	*6%*
2. compost and other appl.	*2%*	*0%*	*2%*	*0%*	*0%*	*–*	*0%*	*1%*	*2%*	*2%*

Romania	2010	2011	2012	2013	2014	2015	2016	2017	2018	Multi-year AVG
3. landfill	*49%*	*47%*	*50%*	*68%*	*75%*	*50%*	*74%*	*59%*	*51%*	*59%*
4. incineration	*–*	*–*	*0%*	*–*	*1%*	*0%*	*0%*	*0%*	*0%*	*0%*
5. other	*2%*	*1%*	*2%*	*27%*	*17%*	*19%*	*19%*	*28%*	*28%*	*14%*
Disposal total	55%	50%	57%	100%	100%	74%	100%	100%	100%	82%
Produced-disposed gap	45%	50%	43%	0%	–	26%	–	–	–	18%
Production TOTAL	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**

17. Table: Sewage sludge production and disposal in Romania (%)

3.1.9 Moldova

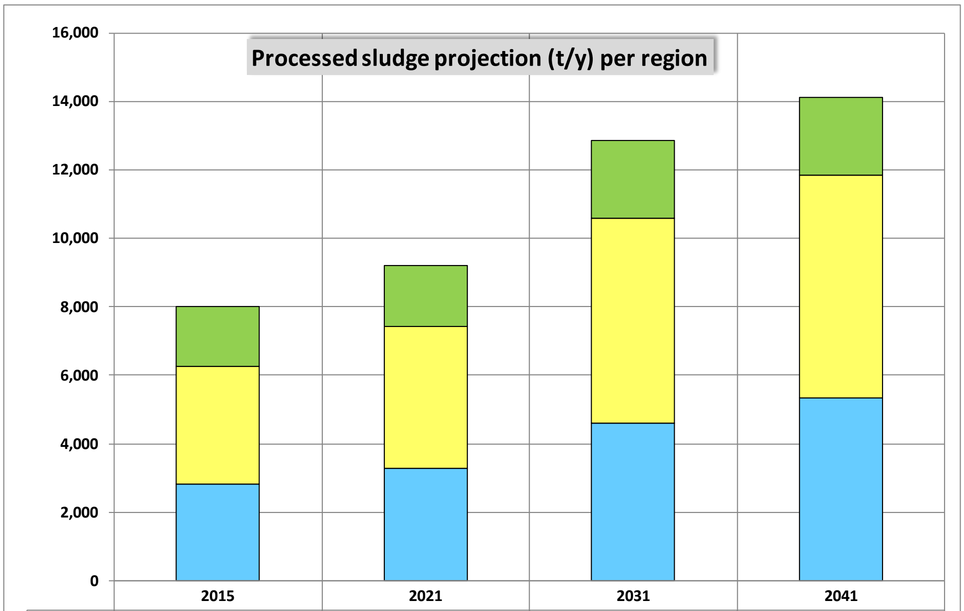
No sufficient data were found regarding Moldova.

3.1.10 Montenegro

The Municipal Wastewater Management Plan of Montenegro[17] was completed for the 2020-2023 period in 2019. Treatment and application of sewage sludge differs by regions. There are regions where sludge treatment is yet to be completed (Herceg Novi), in other regions sludge is treated by dewatering, lime stabilization and reed beds. Sludge disposal options mostly consists of landfilling, although it appears that the regional sanitary landfill operators do not accept the processed and stabilised sludge. Sludge management seems to be well and clearly regulated, yet -the actual established practice is far from ideal and it needs urgent attention and proper solutions. Although the potential in agricultural use is clear, it has not been introduced in legislations. As for export, Budva and Tivat/Kotor regions are reported to export the treated sewage sludge to Albania.

The Sludge Disposal Study for the Coastal Area of Montenegro was also completed and analysed land-based, product based, energy recovery and disposal methods of sludge. Findings showed that due to limited capacity of use of the sludge, additional treatment of sewage sludge is required. Further treatment methods were also proposed in the study such as treatment in reed beds, composting, solar drying and thermal drying. With new treatment methods the volume of dry sludge should decrease and application can become easier.

[17] Ministry of Sustainable Development and Tourism (2018): Municipal Wastewater Management Plan of Montenegro (2020-2035), pp 179.; https://mrt.gov.me/en/ministry/211407/Municipal-Wastewater-Management-Plan-of-Montenegro-2020-2035.html



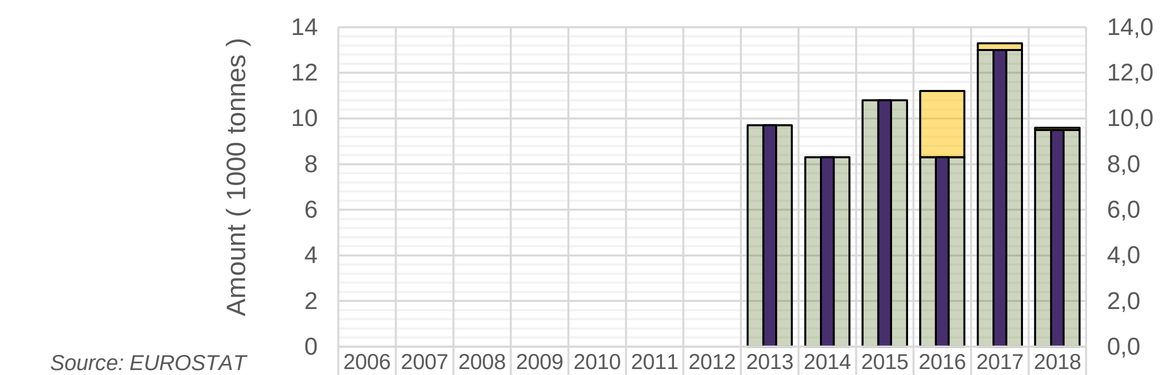
	2015	2021	2031	2041
Northern	1,730	1,771	2,273	2,275
Central	3,432	4,157	5,970	6,483
Coastal	2,830	3,269	4,610	5,348

10. Figure: Processed sewage sludge projection (t/y) per region in Montenegro[18]

3.1.11 Serbia

EUROSTAT data for Serbia is available from 2013, and since then, the country produced approximately 10 thousand tonnes of sewage sludge every year. All of the produced sludge was disposed of except for 2016 and 2017, the only disposal method is landfilling. According to the Sava Committee Serbia's sludge management strategy is being prepared at the moment, therefore more sufficient information will be available in the future.

[18] Ministry of Sustainable Development and Tourism (2018)



	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Produced-disposed gap*	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	2,9	0,3	0,1
Disposal total								9,7	8,3	10,8	8,3	13,0	9,5
1. agricultural use													
2. compost and other appl.													
3. landfill								9,7	8,3	10,8	8,3	13,0	9,5
4. incineration													
5. other	0,0	0,0	0,0	0,0									

11. Figure: sewage sludge production and disposal in Serbia

**export/import or unknown: Gap between the amounts of "Production total" and "Disposal total" calculated on the bases of EUROSTAT data is minor, the quantities nearly equal.*

Serbia	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Production total (EUROSTAT)	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**9,7**	**8,3**	**10,8**	**11,2**	**13,3**	**9,6**
Disposal total (EUROSTAT)	0	0	0	0	0	0	0	9,7	8,3	10,8	8,3	13	9,5
Produced-disposed gap (calc.)	0	0	0	0	0	0	0	0	0	0	2,9	0,3	0,1

18. Table: Calculation of "Produced-disposed gap", Serbia, thousand tonnes

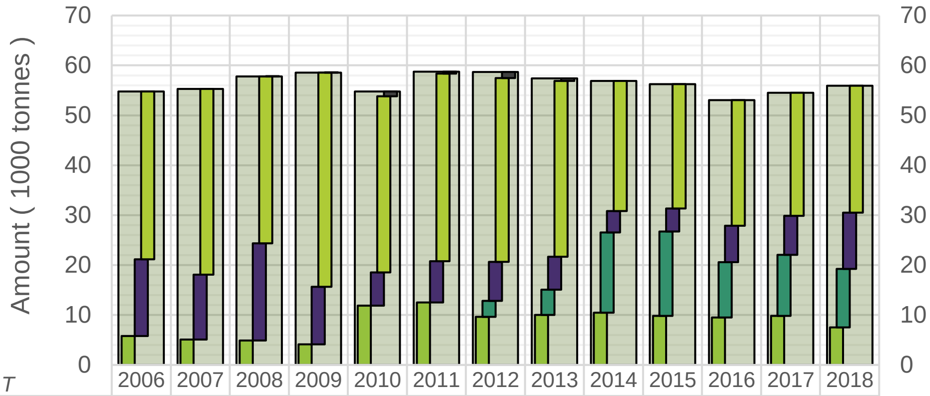
The data of years 2010-2018 in percentage are shown in the next table.

Serbia	2010	2011	2012	2013	2014	2015	2016	2017	2018	Multi-year AVG
1. agricultural use	-	-	-	–	–	–	–	–	–	-
2. compost and other appl.	-	-	-	–	–	–	–	–	–	-
3. landfill	-	-	-	*100%*	*100%*	*100%*	*74%*	*98%*	*99%*	*95%*
4. incineration	-	-	-	–	–	–	–	–	–	-
5. other	-	-	-	–	–	–	–	–	–	–
Disposal total	-	-	-	100%	100%	100%	74%	98%	99%	95%
Produced-disposed gap	-	-	-	–	–	–	26%	2%	1%	9%
Production TOTAL	**-**	**-**	**-**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**

19. Table: Sewage sludge production and disposal in Serbia (%)

3.1.12 Slovakia

According to the National Chapter of the UWWTD (2016) the amount of sludge produced in Slovakia decreased between 2011 and 2016, although EUROSTAT data suggests that it has been increasing again since. The sludge is reported to be mainly disposed of by composting and other applications. The remaining sludge is incinerated, treated with other technologies or goes to landfill.



Source: EUROSTAT

	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Produced-disposed gap*	0	0	0	0	0	0	0	0	0	0	0	0	0
Disposal total	55	55	58	59	55	59	59	57	57	56	53	55	56
1. agricultural use	0	0	0	0	1	0	1	1	0	0	0	0	0
2. compost and other appl.	34	37	33	43	35	38	37	35	26	25	25	25	25
3. landfill	15	13	19	12	7	8	8	7	4	5	7	8	11
4. incineration	0	0	0	0	0	0	3	5	16	17	11	12	12
5. other	6	5	5	4	12	13	10	10	10	10	10	10	8

12. Figure: Sewage sludge production and disposal in Slovakia

**export/import or unknown: Gap between the amounts of "Production total" and "Disposal total" calculated on the bases of EUROSTAT data is zero, because the quantities are equal.*

Slovakia	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Production total (EUROSTAT)	**54,78**	**55,3**	**57,82**	**58,58**	**54,76**	**58,72**	**58,71**	**57,43**	**56,88**	**56,24**	**53,05**	**54,52**	**55,93**
Disposal total (EUROSTAT)	54,78	55,3	57,82	58,58	54,76	58,72	58,71	57,43	56,88	56,24	53,05	54,52	55,93
Produced-disposed gap (calc.)	0	0	0	0	0	0	0	0	0	0	0	0	0

20. Table: Calculation of "Produced-disposed gap", Slovakia, thousand tonnes

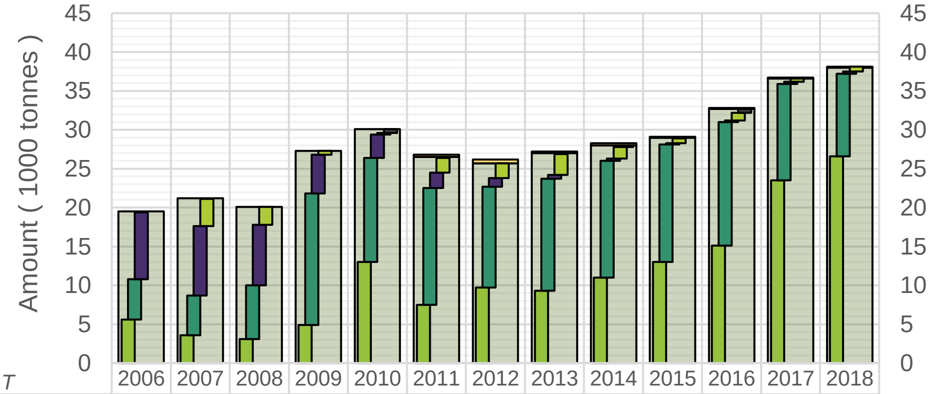
The data of years 2010-2018 in percentage are shown in the next table.

Slovakia	2010	2011	2012	2013	2014	2015	2016	2017	2018	Multi-year AVG
1. agricultural use	*2%*	*1%*	*2%*	*1%*	–	–	–	–	–	*0%*
2. compost and other appl.	*64%*	*64%*	*63%*	*61%*	*46%*	*44%*	*47%*	*46%*	*46%*	*57%*
3. landfill	*12%*	*14%*	*13%*	*12%*	*8%*	*8%*	*14%*	*14%*	*20%*	*17%*
4. incineration	–	–	*5%*	*9%*	*28%*	*30%*	*21%*	*22%*	*21%*	*10%*
5. other	*22%*	*21%*	*17%*	*17%*	*18%*	*18%*	*18%*	*18%*	*13%*	*12%*
Disposal total	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Produced-disposed gap	–	–	–	–	–	–	–	–	–	–
Production TOTAL	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**

21. Table: Sewage sludge production and disposal in Slovakia (%)

3.1.13 Slovenia

According to the National Chapter of the UWWTD (2016) Slovenia was yet to reach the target for the collection and treatment of wastewater, 11 agglomerations still had no treatment plant in place. Sewage sludge is mostly composted or incinerated and it is known that sludge from the Maribor WWTP were exported to Hungary that might appear in class "other".



Source: EUROSTAT

	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Produced-disposed gap*	0	0	0	0	0	0	1	0	0	0	0	0	0
Disposal total	20	21	20	27	30	27	26	27	28	29	33	37	38
1. agricultural use	0	0	0	0	1	0	0	0	0	0	1	0	0
2. compost and other appl.	0	4	2	1	0	2	2	3	2	1	1	0	1
3. landfill	9	9	8	5	3	2	1	1	0	0	0	0	0
4. incineration	5	5	7	17	13	15	13	14	15	15	16	12	11
5. other	6	4	3	5	13	8	10	9	11	13	15	24	27

13. Figure: Sewage sludge production and disposal in Slovenia

**export/import or unknown: Gap between the amounts of "Production total" and "Disposal total" calculated on the bases of EUROSTAT data is zero, because the quantities are equal.*

Slovenia	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Production total (EUROSTAT)	**19,5**	**21,2**	**20,1**	**27,3**	**30,1**	**26,8**	**26,2**	**27,2**	**28,3**	**29,1**	**32,8**	**36,7**	**38,1**
Disposal total (EUROSTAT)	19,5	21,2	20,1	27,3	30,1	26,5	25,7	27	28	29	32,7	36,6	38
Produced-disposed gap (calc.)	0	0	0	0	0	0,3	0,5	0,2	0,3	0,1	0,1	0,1	0,1

22. Table: Calculation of "Produced-disposed gap", Slovenia, thousand tonnes

The data of years 2010-2018 in percentage are shown in the next table.

Slovenia	2010	2011	2012	2013	2014	2015	2016	2017	2018	Multi-year AVG
1. agricultural use	*2%*	–	–	–	*1%*	–	*2%*	–	–	*0%*
2. compost and other appl.	*0%*	*7%*	*7%*	*10%*	*5%*	*2%*	*3%*	*1%*	*2%*	*5%*
3. landfill	*10%*	*7%*	*4%*	*2%*	*1%*	*1%*	*1%*	*1%*	*0%*	*11%*
4. incineration	*45%*	*56%*	*50%*	*53%*	*53%*	*52%*	*48%*	*34%*	*28%*	*44%*
5. other	*43%*	*29%*	*37%*	*34%*	*39%*	*45%*	*46%*	*64%*	*70%*	*35%*
Disposal total	100%	99%	98%	99%	99%	100%	100%	100%	100%	100%
Produced-disposed gap	–	1%	2%	1%	1%	0%	0%	0%	0%	0%
Production TOTAL	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**

23. Table: Sewage sludge production and disposal in Slovenia (%)

3.1.14 Ukraine

According to the National Standard of Ukraine the quantity of sludge is approximately 30% of the generated wastewater. Sludge is mostly treated by drying, then it is stored or disposed of. The quantity of sludge reached 1 billion tonnes and it is still growing, therefore big capacities are needed to store it. The areas used for the storage of sludge are continuously exposed to the hazardous substances found in sludge, such as hydrogen sulphide and ammonia which can pollute surface and groundwaters as well as the soil and the air.

Sludge disposal options such as agricultural or forestry use as well as biothermic composting were researched. Sewage sludge can also be disposed of by energy recovery through incineration or biogas utilization. Ukraine also uses the sewage sludge as an alternative fuel, although the use is only permitted for industrial use and forbidden for the residents. Besides the above presented information, no detailed publicly available data were found on the specific methods of sewage management in the Ukraine.

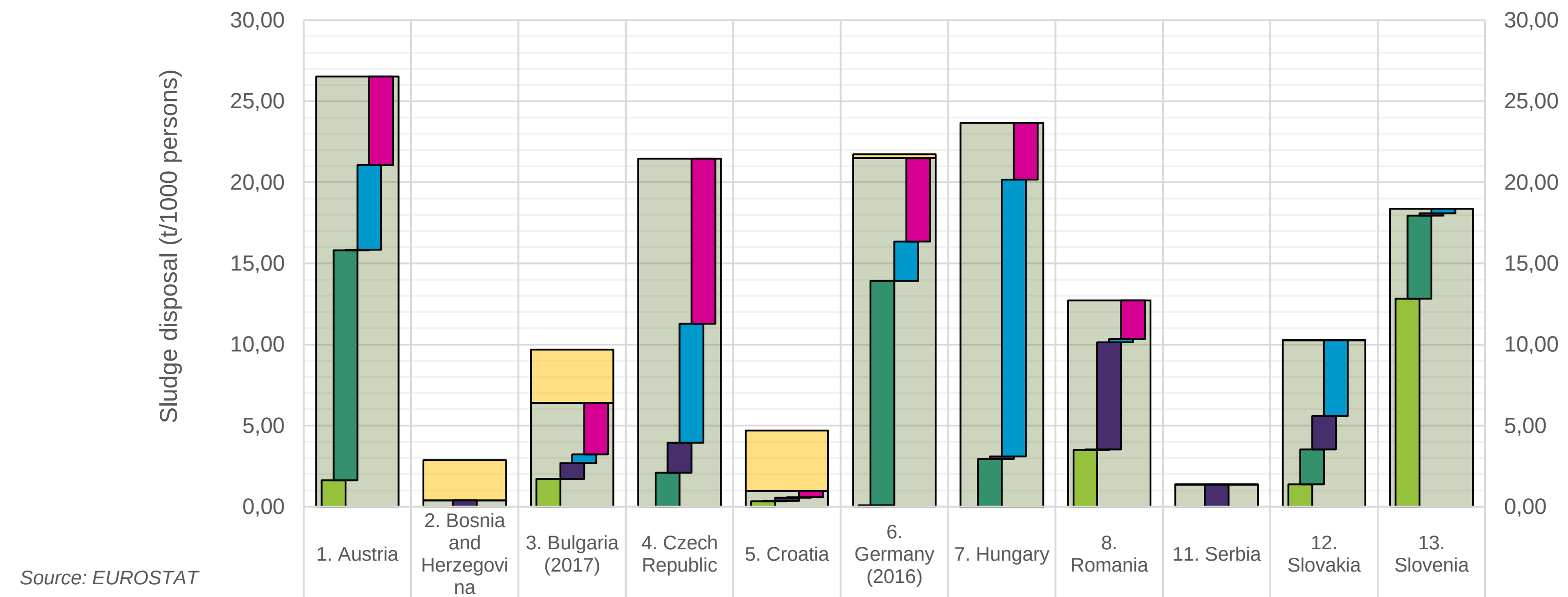
Preparatory study on sewage sludge management in the Danube Region

3.2 Common techniques in the Danube Region – a comparative summary

Country/ region	Pop. million persons	Strategy exists? date-of-issue/no	Sludge produced, thousand t	Sludge treatment and recovery techniques					
				Total disposal %	Agriculture %	Compost and other appl. %	Landfill, %	Incineration, %	Other %
Austria	8,84	Biowaste strategy (2014.)	234	100	21	20	0	53	6
Bosnia and Herzegovina	3,32		9,5	35	-	-	35	-	-
Bulgaria	7,13		65,8	67	33	6	10	-	18
Czech Republic / Moravia	10,63		228	100	47	34	9	10	-
Croatia	4,17		19	21	10	0	4	-	7
Germany	82,35	Sewage sludge management (2016.)	1 795	99	24	11	-	64	-
Hungary	9,81	Sludge Treatment and Recovery Strategy (2013.)	218	106	15	77	1	13	-
Romania	19,59	National strategy for sewage sludge management (2011 – under revision)	248	100	19	2	51	-	28
Moldova	2,66		-	-	-	-	-	-	-
Montenegro	0,62	M. Wastewater Management Plan of MN (2019)	-	-	-	-	-	-	-
Serbia	6,95		9,6	99	-	-	99	-	-

Country/ region	Pop. million persons	Strategy exists? date-of-issue/no	Sludge produced, thousand t	Sludge treatment and recovery techniques					
				Total disposal %	Agriculture %	Compost and other appl. %	Landfill, %	Incineration, %	Other %
Slovakia	5,44		56	100	-	46	20	21	13
Slovenia	2,07		38	100	-	2	0	28	70
Ukraine	44,39		-	-	-	-	-	-	-

24. Table: Sludge management in the EUSDR countries – annual figures (2016 / 2017 / 2018)

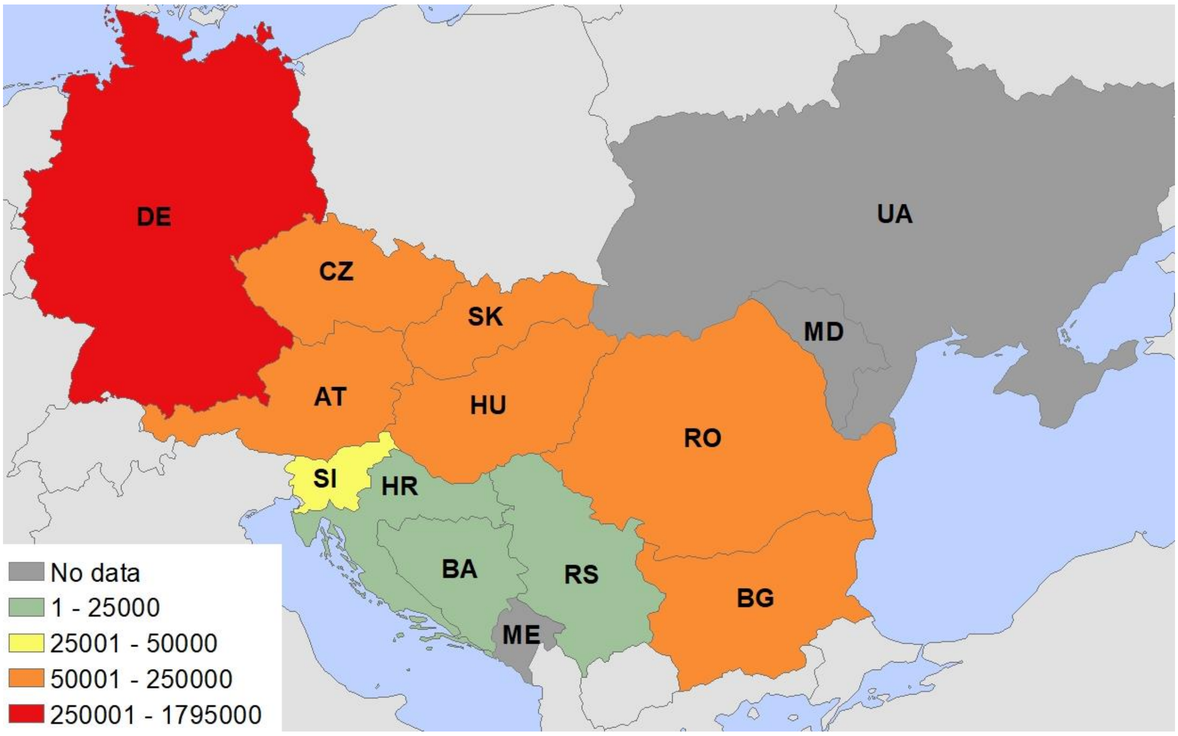


	1. Austria	2. Bosnia and Herzegovina	3. Bulgaria (2017)	4. Czech Republic	5. Croatia	6. Germany (2016)	7. Hungary	8. Romania	11. Serbia	12. Slovakia	13. Slovenia
Produced-disposed gap*	0,00	2,47	3,29	0,00	3,74	0,25	-1,38	0,00	0,01	0,01	0,00
Disposal total	26,52	0,39	6,40	21,47	0,97	21,49	23,67	12,72	1,36	10,26	18,37
1. agricultural use	5,45	0,00	3,18	10,19	0,38	5,13	3,49	2,38	0,00	0,00	0,00
2. compost and other appl.	5,24	0,00	0,54	7,34	0,04	2,43	17,08	0,21	0,00	4,67	0,29
3. landfill	0,03	0,39	0,96	1,84	0,19	0,00	0,15	6,59	1,36	2,07	0,14
4. incineration	14,18	0,00	0,00	2,10	0,02	13,85	2,95	0,04	0,00	2,14	5,11
5. other	1,63	0,00	1,72	0,00	0,34	0,08	0,00	3,50	0,00	1,38	12,83

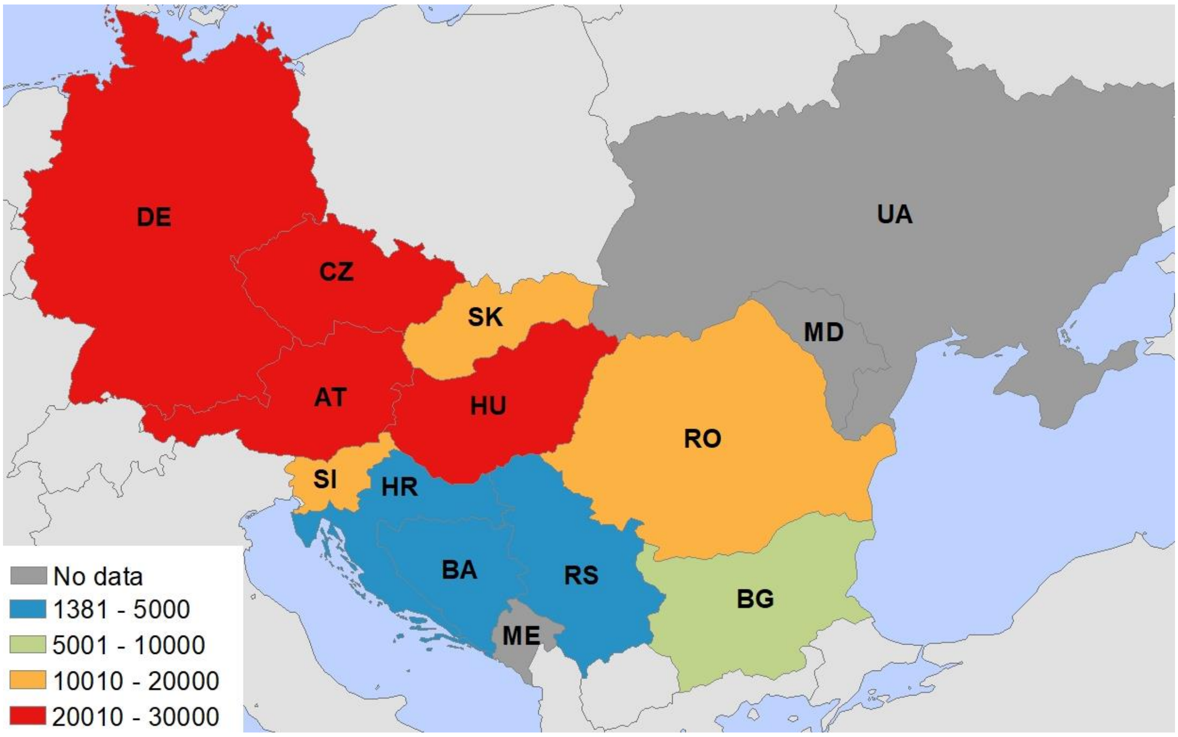
14. Figure: Sludge management in the EUSDR countries – annual figures (2016 / 2017 / 2018)

All data presented in the above figure and table 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.

Preparatory study on sewage sludge management in the Danube Region



15. Figure: Annual sludge production in the EUSDR countries, tonnes, data: EC 2016, 2018



16. Figure: Annual sludge production per million inhabitants in the EUSDR countries, tonnes, data: EC 2016, 2018

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 rapidly increases. In many cases the sludge cannot be treated or disposed of yet properly because of technical difficulties and financial gaps.

The first obvious solution to sludge management is landfilling or storing as seen in 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.

Figure 13 of the study compares quantities of sludge per 1000 persons as well as disposal methods in the countries examined, it contains EUROSTAT data from 2018 except for Germany where 2016, and Bulgaria, where 2017 data were used as it was the latest available. In Austria, all of the produced wastewater is collected and treated. The situation in Germany is similar, only 0,1% of wastewater collected should still undergo secondary treatment which can still cause sludge quantities to increase. Quantities are expected to increase to approximately 30 tonnes/1000 persons similarly to Austria. In Germany sludge disposal by landfilling is eliminated entirely, the sludge produced is mostly incinerated followed by use in agriculture and composted in smaller quantities.

In Hungary, a negative gap can be seen between the produced and disposed amounts. These data are distorted by import and storage of sludge from previous years that are being disposed of in the examined year. In the case of Bulgaria, Croatia and Bosnia and Herzegovina the gap is most likely caused by the fact that the volume of sewage sludge is increasing while the capacities for treatment or disposal are still being planned or built.

For better understanding of the data showed in this study and conclusions drawn from it, definitions of disposal methods are to be cleared 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.

In conclusion, it can be said that sludge treatment and disposal techniques in the Danube Region are very much diverse in many cases there is not enough data to actually see the trends in which the region is heading. To create a more comprehensive viewpoint on the matter of sludge management further data inquiry and research are needed.

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 is 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[19], 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 trend is increasing; it was estimated that in 2018 the total amount of export/import increased to 414 thousand tonnes. 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%). **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[20]; 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.

[19] 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

[20] Vecer.com

4 Best practices

4.1 Best available techniques

The Best Available Techniques (BAT) Reference Document for Common Waste Water and Waste Gas Treatment/Management System in the Chemical Sector[21] 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)[22] 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.**

	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	Not applicable to inorganic sludge. The necessity for conditioning depends on the sludge properties and on the

[21] 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

[22] 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
		sludge thickening/dewatering.	thickening/dewatering equipment used.
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.

25. 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.

4.2 Good practices for utilisation

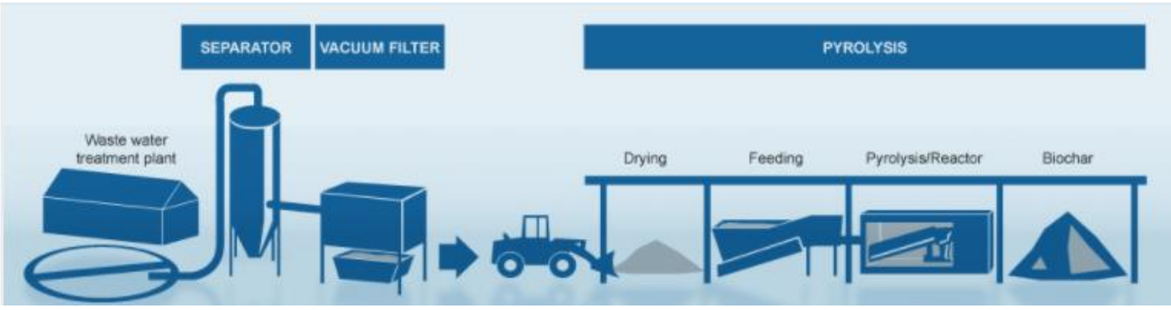
ECO-BIS – Developing more environmentally-friendly and efficient waste water treatment plants and recycling sewage sludge into a high added value biochar material[23]

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:



17. Figure: The process of ECO-BIS technology

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

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:

	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

26. Table: Performance indicators for the experimental plant
Source: Kalogeo process[24]

[24] 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

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 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.

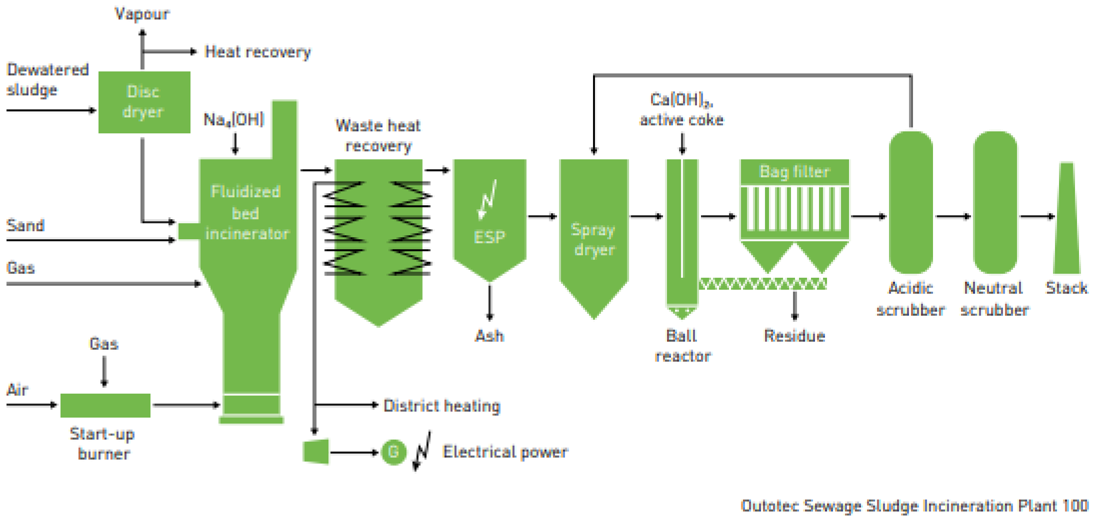
Outotec Sewage Sludge Incineration Plant, Switzerland

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



18. Figure: The technological chain of the incinerator plant
Source: OUTOTEC, 2020[25]

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:

[25] https://www.outotec.com/products-and-services/technologies/energy-production/sludge-incineration-plant/

	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

27. 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 ºC 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[26]

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 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:

[26] 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;

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

28. 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.

	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

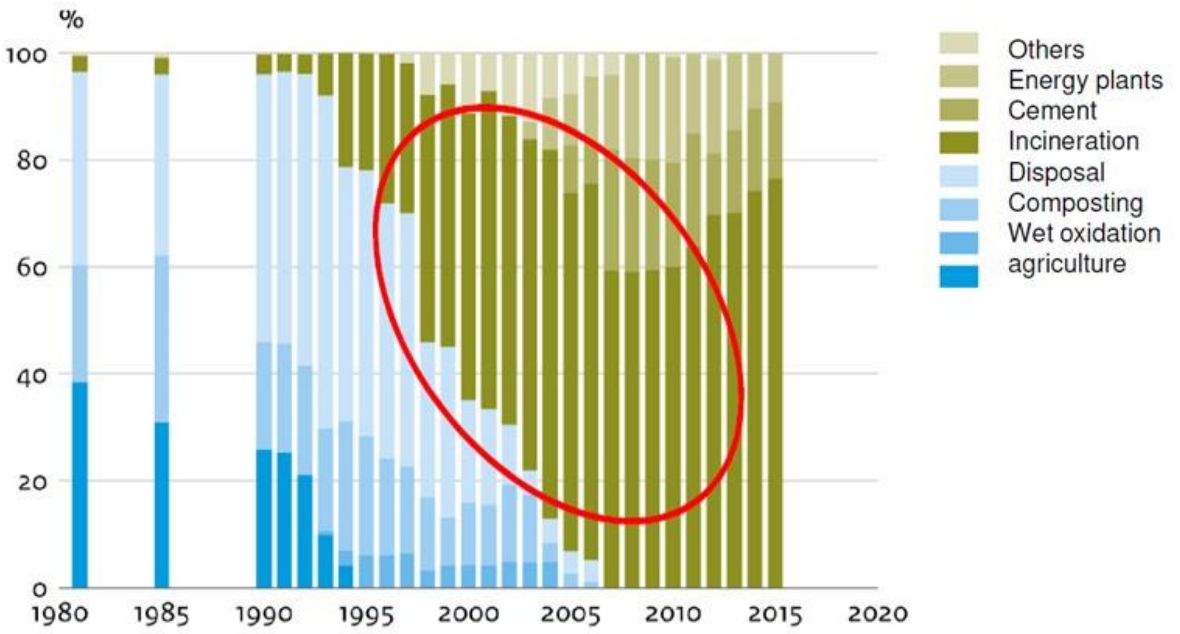
29. Table: Contaminants related to the agricultural use of sludge
Source: SCS, 1998; Naturvårdsverket, 1994 in KTH, 2018

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[27]:



19. 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 (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,

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

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[28]. 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)[29].

[28] 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

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

5 Major challenges in sludge management

5.1 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 Urban 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.

5.2 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. Naturally, the existence / coverage of sewers and treatment plants, according to the studies recently published[30], 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 and according to the latest report, treatment coverage grew up to 60% 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 / stormwater management. In the older unified sewage

[30] 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

systems, the rainwater 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 separated sewage collectors, changing/improving sludge quality considerably over time.

Another aspect of sludge production besides coverage and technologies is the number of population 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[31] 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:

	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

30. 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[32] that the occurrence of

[31] 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
[32] 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 Science and Technology; Volume 49, 2019 - Issue 16; https://www.tandfonline.com/doi/full/10.1080/10643389.2019.1579619?src=recsys

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[33] and the living environments.

5.3 Financial considerations of sludge management

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[34] 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
- Cost of waste disposal

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[33] 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

[34] 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

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:

	2 000-10 000 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

31. 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%), aerob stabilisation, compost for agricultural use complying with pollution limits

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

Technology 3.: Pre-treated (water c.: 40-60%), aerob 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, aerob 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, anaerob 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:

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

32. Table: Planned incinerators' capacities and estimated investment costs in Poland (potential co-burning sludge) Source: Cyranka et al. 2016[35]

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[36] 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 sectors. As a result, thermal / energetic recovery of sludge becomes feasible. Thus, in these

[35] 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

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

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. This financial-economic environment was realised, for example, during the preparation of the Hungarian Sewage Management Strategy, where cost-benefit analyses were carried out to support decisions on the possible recovery solutions. 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).

6 Summary and recommendations

6.1 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 rapidly in the last decade. 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; and in the downstream countries waste water treatment recently gained impetus. 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.

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 increases rapidly 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.

6.2 Possible themes of common interest

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[37])
- 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

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
- 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

37 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

- 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.

6.3 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[38]) 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

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

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,
  - 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.

6.4 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 and dissemination of know-how 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

As an immediate action with special reference to the ongoing legislative processes in the EU, it is recommended that according to the result of the early discussions, the EUSDR participates in the public consultation processes related to the revision of the wastewater regulation and the regulation on the use of sludge in agriculture and encourages all interested stakeholders to do so.

Annex: Basic definitions[39]

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.

[39] 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[40]

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.

[40] 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/