Tampere University of Applied Sciences

Sewage Sludge Treatment in Bulgaria

Identifying suitable European techniques for improving the Bulgarian model

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ABSTRACT

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In Bulgaria in the period between 2009 and 2018, the outflow of sludge has risen by more than 36%. Despite the established sewer sludge management plans, it is still not disposed of fully and sustainably.

The objective of this thesis was to carry out a literature review of scientific articles, Bulgarian official reports and plans, and suggest how to improve the Bulgarian model through introduction of European good practices.

An important finding in the background research section was that landfilling, agricultural utilization, and vermicomposting are very common disposal methods in Bulgaria. Anaerobic digestion, incineration of sludge and co-incineration of sludge with MSW, as well as pyrolysis were identified as good European practices.

The results show that there were four anaerobic digestion units in Bulgaria in 2017. Incineration and co-incineration is only applied in three cement plants and four co-incinerators. Pyrolysis is still not applied anywhere in Bulgaria. The advantages and disadvantages of the European practices were evaluated through SWOT analysis-like criteria.

Lastly, a conclusion could be drawn that the current treatment techniques should be deeply improved in order to meet the sustainability and disposal demands. As a new treatment technique, it could be advised for the country to invest in a pyrolysis installation, even if it is only on a pilot scale.

Key words: wastewater sludge, sewer sludge, sludge treatment

CONTENTS

GLOSSARY

BAT	best available techniques
CO_2	carbon dioxide
DM	dry matter
EU	European Union
e.V	registered association (German: eingetragener Verein)
GHG	green house gases
HCN	hydrogen cyanides
MSW	municipal solid waste
MWWTP(s)	Municipal wastewater treatment plant(s)
NSPST	National strategic plan for sludge treatment in the period 2014-2020
OM	organic material
RE	resident equivalent
TPP	thermal power plants
TUNI Andor	Tampere university Library's discovery service
t/DM	tonnes/dry matter

1 INTRODUCTION

During the period between 2014 and 2019, the number of municipal wastewater treatment plants (MWWTPs) in Bulgaria and the amount of treated wastewater has increased due to pressure and financing from the European Commission. Up until 2019, 110 MWWTPs have been newly build or old ones have been remediated. (MOEW 2019) With that, the amount of outflow of sludge has risen by more than 36% in the period between 2009-2018 (Executive Environment Agency 2011, 2019). The expectations are for these amounts to continue to grow with a fast pace and the problem with sludge disposal to become a great concern for all interested parties – MWWTP operators, citizens, and authorities. In addition to the current problematic situation, the government has planned to open up MWWTP for all agglomerations of 2000 resident equivalent (RE) by 2023. (NSPST 2014)

In this thesis, different technologies for pre-treatment and treatment of sludge, as well as utilization methods for the treated sludge are overviewed in order to propose improvement to the Bulgarian practice. Currently the MWWTP sludge is widely used as soil improver by agricultural units in Bulgaria, although often the sludge is not properly pre-treated or analyzed (NSPST 2014). Due to the lack of comprehension of the hazards, which this model could hide, it is advised for it to not be largely implemented in the near future in order to prevent environmental and human-health threats (Expert working group 2021). Other methods include thermal drying, gasification, or landfill disposal of the sludge. The latter being the lowermost principle of waste treatment in the waste treatment hierarchy it is preferred for it to be discouraged. (Indzhova 2021)

In order to avoid landfilling or combustion for sludge disposal, better pre-treatment principles or more modern and efficient solutions should be introduced. Such pre-treatment technologies include sludge stabilization, dehydration, or drying, after which the sludge is suitable for treatments like energy recovery or pyrolysis. (Expert working group 2021) The European commission has adopted various best available techniques (BAT) throughout the years for sludge treatment. Many European Union (EU) countries are trying to comply with them by encouraging and supporting businesses and companies to develop treatment units, which eventually supply the end customers with stabilized safe-to-use dewatered sludge that can find implementation in various spheres. (Milieu Ltd, WRc and RPA 2010). As the sludge, taken into account in this thesis, originates from non-hazardous sources – municipalities, it is high in organic substances and nutritious solids, which are safe to be reused. Should these organic compounds and nutrients be recovered, they can find safe application in agriculture, land recovery and other spheres without raising health or negative environmental consequences. (Expert working group 2021)

Research questions:

1. Which are the most common treatment technologies in Bulgaria?
2. Which are the most widespread technologies in the EU?
3. Which EU good practices could be implemented in the Bulgarian model?

2 SCOPE

In order to meet the water treatment demands, the developed and developing countries are relying on emerging new and more efficient MWWTPs, which aim to ensure the safely recirculation of water back to the environment without causing serious environmental strain. As a side stream of these plants, around 10 million tons DM of sludge are formed annually in the 26 EU member states. (Lepez 2016) To fulfil the modern demands for environmental compliance and avoid ecological damage, the above-mentioned countries have worked out numerous laws and directives to support and encourage the development of technologies and operation units for pre- and post-treatment of the municipal sewage sludge. (European Commission n.d.)

The aim of this thesis is to review the current situation of sludge treatment in Bulgaria and to research the present available techniques and technologies, practices and encouraged actions by the EU. A conclusion of the most suitable technique for Bulgaria will be drawn based on comparison of some of the available technologies and their juxtaposition with one another. In figure 1 below, a flowchart of the main treatment processes is shown. The techniques in green and blue are tackled ones in this thesis. The techniques in green are the focus ones for Bulgaria, and in blue are the focus ones as European good practices.

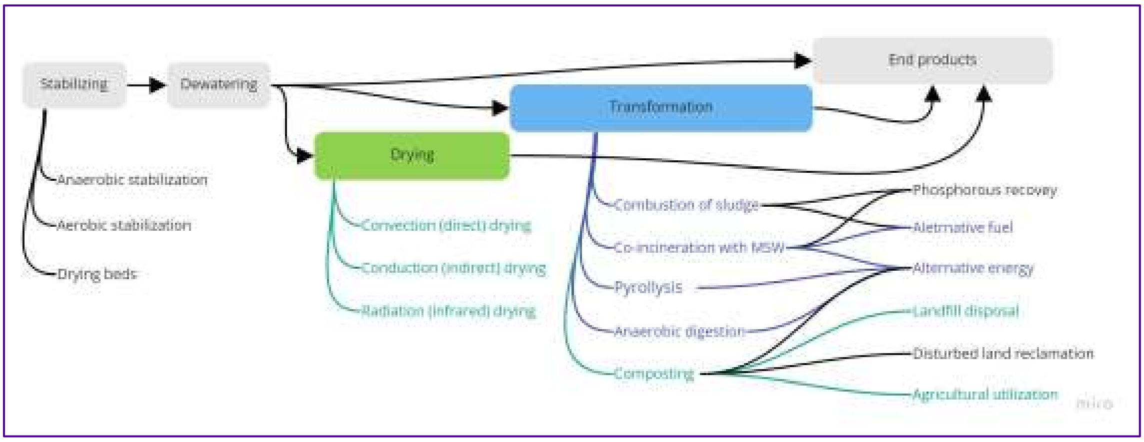

FIGURE 1. Treatment techniques taken into consideration (Umweltbundesamt 2013, modified)

3 METHODS AND MATERIALS

The research process for this thesis includes a systematic review of scientific articles, governmental reports and articles on waste management and action plans for water reuse, and investigation of the European commission publications on related topics. Additionally, an interview with a waste management expert from Bulgaria has been conducted and analysed. Apart from the mentioned qualitative evaluation, quantitative methods were also included in the data collection methods through statistical research and data analysis.

The Bulgarian environmental authorities produce and publish various research pieces and action plans regarding water, wastewater, and sludge management every few years. Such plans provided by the Basin directorates, Executive Environment Agency, Ministry of Environment and Water, and other governmental bodies have been the main source of current information about the situation in Bulgaria. Only a few of these pieces of research or parts of them have been translated into English. The main national reports used as information sources in this thesis are, but are not limited to:

- National strategic plan for sludge treatment in the period 2014-2020;
- Consultancy programme for development of strategy for improving the water supply and sewer system enterprises;
- Expert report on treatment of municipal wastewater treatment plants' sludge.

To further support the gathered official information, other published and unpublished research and analysis pieces have been used as reference data sources. Such articles include MWWTPs' statistical data and development plans, other expert works, collaboration research programmes with other EU countries and departments, and related articles accessible through TUNI Andor. Unpublished source of relevant information for this thesis is discussion workshops held in Bulgaria in the summer 2021 with experts in the sphere of agriculture, waste management, water supply management, sustainable development, and environmental management.

In addition to these sources, an interview with a waste management expert from a renowned Bulgarian environmental management company has been conducted. The interviewee, Nedka Indzhova, has a 12-year experience in the sphere of environmental management with a focus on waste management and hazardous substances. The interview was conducted and recorded on 18.8.2021 in Plovdiv, Bulgaria. The transcription of the recording is presented in Appendix 1. Apart from the recorded interview, other discussion sessions have been held with Mrs. Indzhova and the expert working group, and the collected information from these meetings is used as alternative source in this thesis. In the interview, a few topics were shortly discussed:

- Expert’s background and proof of knowledge on the issue;
- Current problems with sewer sludge in Bulgaria;
- Best available techniques in the sphere according to the expert;
- Vision of the future development of the sphere.

For the evaluation of the gathered information graphs, tables, pictures, and figures are used.

4 BACKGROUND RESEARCH ON SLUDGE TREATMENT IN BULGARIA

4.1 Definition of sludge

By definition, although it may vary depending on the context, sewage sludge is "the solid, semisolid, or slurry residual material that is produced as a by-product of wastewater treatment processes". Usually different types of sludge are formed as a result of primary and secondary chemical, mechanical and/or biological treatment of grey or black water. As to meet the standards for post treatment and for better efficiency, they can be combined. The most important outcomes of sludge treatment are to reduce its volume and to stabilize the reactivity and the organic composition. (Britannica n.d)

According to the Framework Waste Directive "waste" means any substance or object which the holder discards or intends or is required to discard" (Directive 2008/98/EC). The purpose of the List of waste referred to in article 7 of Directive 2008/98/EC is to classify the types of waste through six-digit codes according to their origin and hazardousness. (Document number C (2000) 1147)

For the purpose of this thesis only waste with code *19 08 05 Sludges from treatment of urban waste water* are taken into account. It falls under Chapter 19 – Wastes from waste management facilities, off-site wastewater treatment plants and the preparation of water intended for human consumption and water for industrial use, sub-chapter 08 – wastes from wastewater treatment plants not otherwise specified. (Document number C (2000) 1147)

4.2 Waste treatment hierarchy

The waste treatment hierarchy is the basic principle, which determines the sustainability of waste treatment. It is determined by the Framework Waste Directive (Directive 2008/98/EC) and establishes the following priorities in the context of sewer sludge:

- The primary priority is the prevention of sludge generation;

- As next priorities come the reusing and recycling of sludge, which would allow its safe post-treatment utilization and would make the valuable organic substances easily available;
- When it is not possible to execute one of the above actions, the sludge may be used as secondary energy source to compliment the energy needs of different industrial manufacturing plants and can be utilized as an alternative to fossil fuels;
- Only when one or combination of more of the previous priority means cannot be fulfilled, and temporary storage of the sludge would not raise the possibility for its utilization in the short term, it can be disposed of on specially purposed landfills and upon pre-treatment and stabilization.

The waste management hierarchy is illustrated on Figure 1.

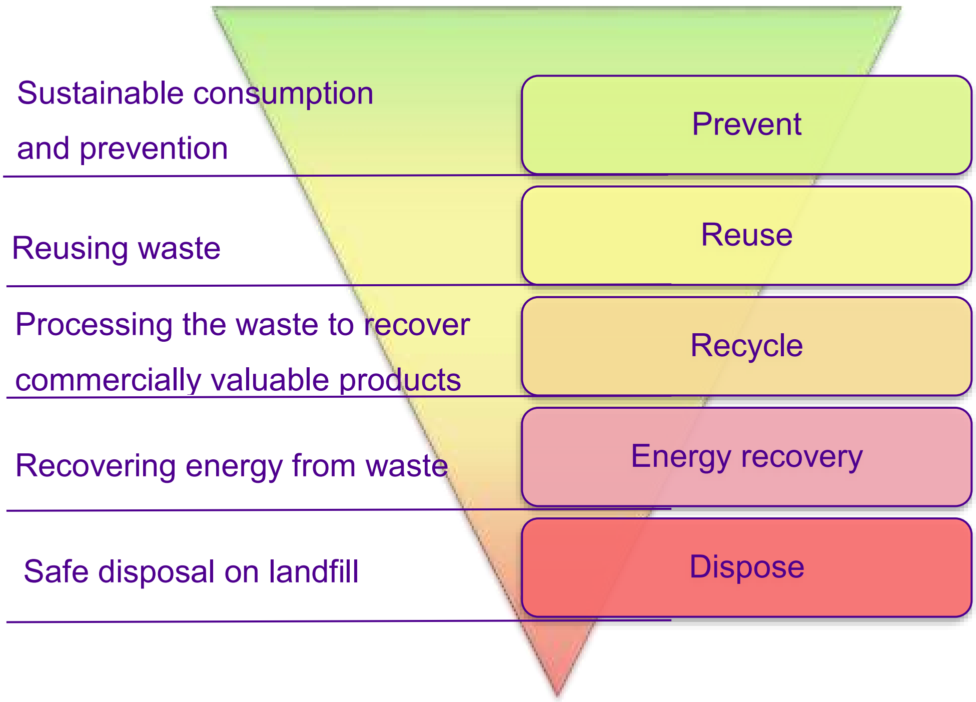

FIGURE 2. Waste management hierarchy (Kuutti 2020, modified)

This hierarchy determines the sequence in which the waste should be treated. Should there be a possibility to perform a higher ranked procedure, an inferior action should be avoided. The hierarchy embodies the principles of circular economy and sustainable use/re-use of materials. In addition, its composition ensures lowering the environmental hazards, improvement of the raw material usage, and proper waste management. (Kuutti 2020) With the current development of the society, landfill disposal is encouraged to be completely avoided. (Expert working group 2021)

4.3 Current sludge treatment situation in Bulgaria

4.3.1 Sewer sludge quantities generated in Bulgaria

According to the reports by the Executive Environment Agency (2011 & 2019) the total amount of generated non-hazardous sludge in 2009 was 36 639 tonnes/dry matter (t/DM) while in 2018 it was 53 082,62 t/DM. In Appendix 2 the quantities of generated non-hazardous sewer sludge by municipal districts in 2018 are presented.

Since there is no official open-source information on the number of MWWTPs, information from various sources, most of which mentioned in Chapter 3, was compiled and it was estimated by the Expert working group (2021) that there are over 140 municipal WWTPs in Bulgaria. The location of the identified ones is presented on the map with the municipal districts numbered in compliance with the table in Appendix 2 (figure 3).

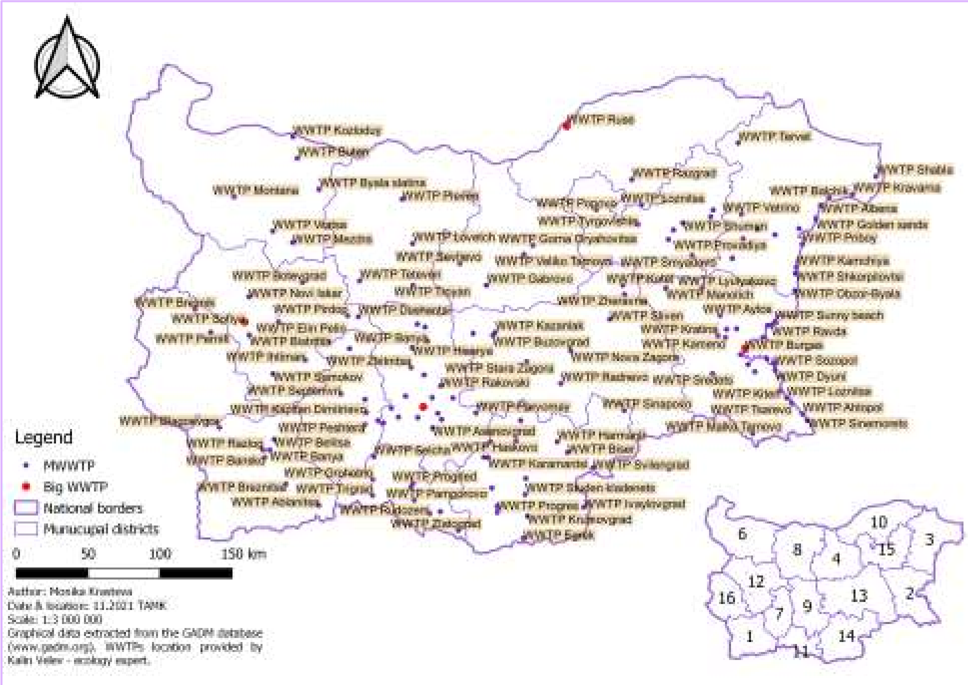

FIGURE 3. MWWTPs location and municipality districts division

The distribution of the plants is uneven throughout the territory. There are more plants located in the southern and eastern areas as they are more populous and have better developed economy in comparison to the northern and western areas. The plants labelled as “big” generate more than 3000 t/DM annually. They are located in the near proximity of the biggest cities and are the ones considered in biggest need of sustainable management for the generated sludge.

In the Executive Environment Agency report (2019) the distribution of the most common means of utilization are presented (Figure 4). On the other hand, in figure 5 is presented the utilization of sludge by 2014 (NSPST 2014).

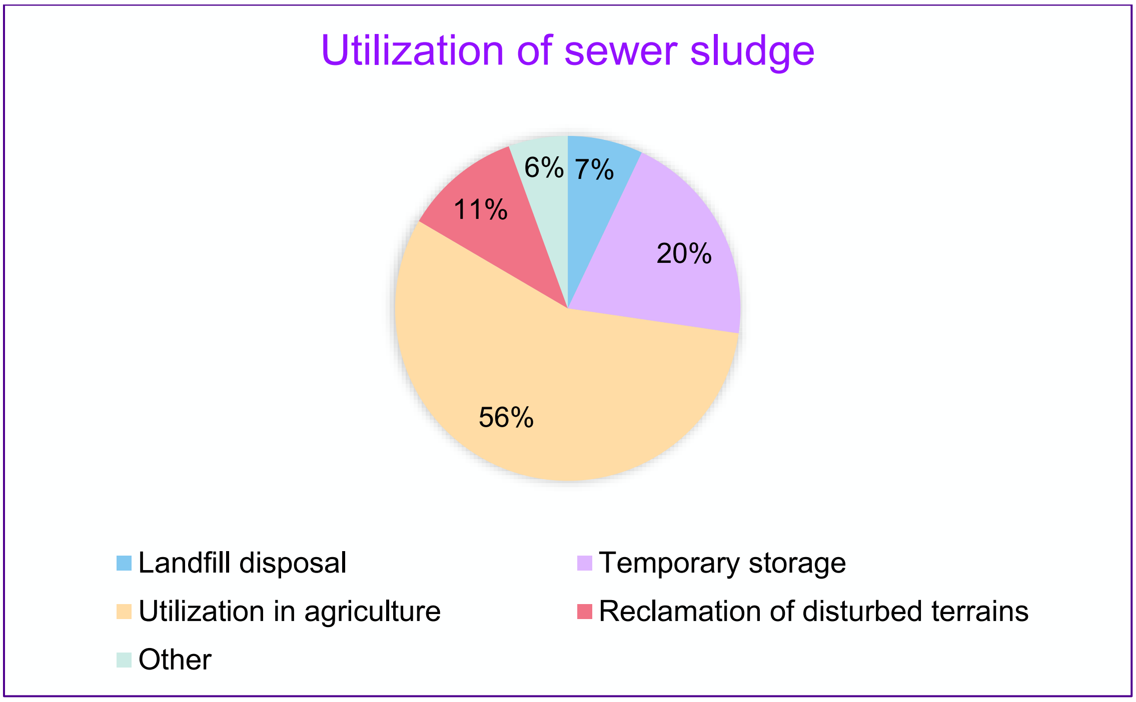

FIGURE 4. Distribution of the utilization means of sewer sludge (Executive Environment Agency 2018, modified)

Under the category "Other" fall, but is not limited to, recycling and material regeneration, and energy recovery (Executive Environment Agency 2019).

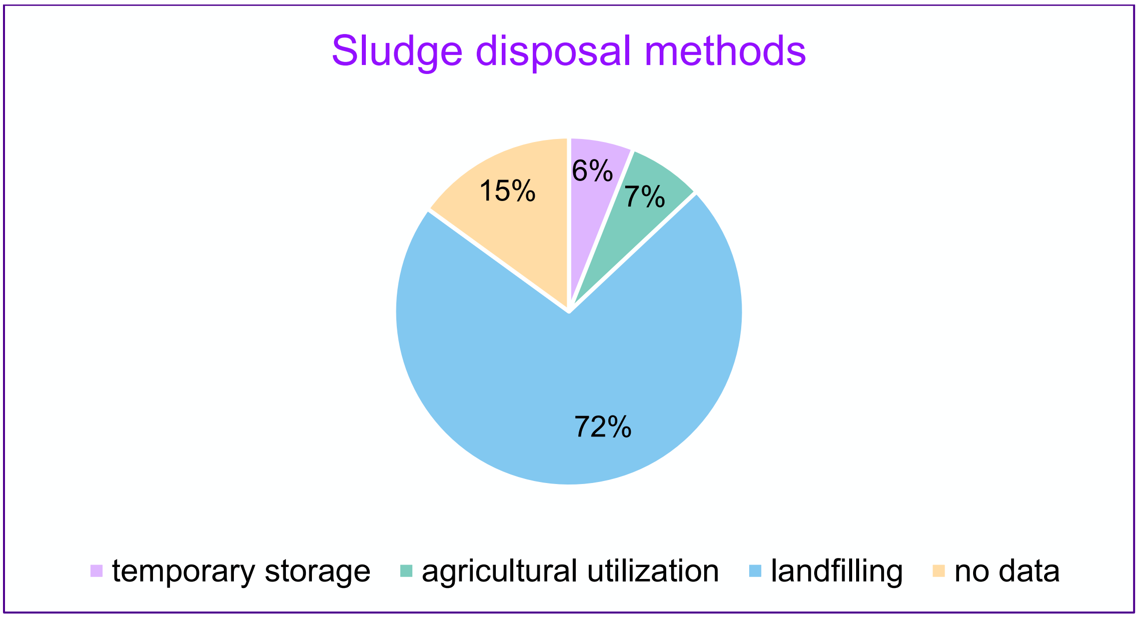

FIGURE 5. Distribution of the utilization means of sewer sludge (NSPST 2014, modified)

The data in figures 4 and 5 has been derived from two official governmental sources. However, it can be seen that it is highly opposing and numerically incomparable. Although the data is for different years – 2014 and 2018, the time period is too short for such a drastic change in the sludge management approaches. The only conclusion than can be certainly deducted from the figures is that the most widespread methods of sludge management are utilization in agriculture and landfilling.

In comparison with the targets outlined in the NSPST, explained in Chapter 4.3.2, the percentage of utilization of sludge as recycling and regenerative material according to the Executive environment Agency is not too far from this target. However, the energy recovery and landfill minimisation are still not meeting the set goals even after the planned year of reaching them. According to the data provided by the Ministry of Environment and Water (Figure 5), the percentage of utilization of sludge as recycling and regenerative material, as well as the percentage of landfilling are highly insufficient to meet the set targets.

The questions related to utilization of sludge in agriculture are often avoided or answered vaguely by the government. This is the case as the closely monitoring the analysis and actual spreading of certified safe sludge is hard to achieve, mainly due to political reasons, corruption, and shortage of staff and high expertise in the control bodies. (Expert working group 2021)

4.3.2 Strategic plan for sludge treatment

Bulgaria is implementing a National strategic plan for sludge treatment in the period 2014-2020 (NSPST). This is the most recent document available, which outlines the techniques and suggested practices with which the MWWTPs operators and waste traders should comply. Some of the targets aimed by the plan are:

- Recycling and material regeneration of MWWTPs sludge by year:
  - 55% until the end of 2016;
  - 65% until the end of 2020.
- Energy recovery of MWWTPs sludge by year:
  - 10% until the end of 2016;
  - 35% until the end of 2020.
- Zero landfill disposal by the end of 2020. (NSPST. 2014)

Currently an incompliance with the Plan’s targets is present all around Bulgaria.

4.3.3 Identification of the reasons for incompliance with NSPST

The following reasons have been identified during the discussion workshops (2021) as most important problems for preventing the MWWTPs operators of meeting the targets:

1. There is no or very little cooperation established between the operators, the municipal authorities, and other interested associations. With the recent creation of a new water and sewer responsible authority in 2020, there has been a positive tendency of increasing efficient water use, wastewater treatment and residual material utilization.
2. Even though there are established action plans for the majority of the MWWTPs, the aims and targets outlined in theme are vague and generic, and do not take into account the specific characteristics of each plant or the local differences in terms of WWTP inflow and sludge outflow. Furthermore, the modern technologies and solutions from the sphere are barely considered.
3. The current most widely spread technique – utilizing sludge, often even raw sludge, in agriculture is highly dependent on legislation and weather conditions. Usually this method can be implemented only during certain times of the year: when the precipitation is in low quantities, weeks before and after sowing crops for which is allowed to be fertilized by sludge, etc.
4. Storing of sludge on the MWWTPs premises until suitable moment for agricultural utilization is weather-condition dependent too and may lead to the occurring of additional biological processes in the sludge piles. Even if the sludge is aimed to be temporarily stored before further usage, it should be pre-treated, stabilized, and the moisture content should be lowered. The most common storage pre-treatment technique is drying the sludge on open fields.
5. Currently, there are no incineration plants on the territory of the any of the MWWTPs. To build such installation a long and time-consuming legal procedure has to be conducted, substantial amount of material resources

have to be provided, and demanding European and national environmental compliance requirements have to be fulfilled. Undertaking all these and many other steps makes the emerging of such incineration plant off-putting for the MWWTPs operators.

6. Even after the adoption and transposition of EU laws into the National legislation, the sludge is considered “a problem of the operator, not a side stream product”. (Indzhova 2021).

Sewer sludge disposal is a substantial and expensive to solve environmental problem, which should be solved as efficiently and as soon as possible. Sludge disposal contributes to half of the total wastewater treatment and if not properly treated it may cause eutrophication, soil pollution, and human and livestock health problems. (European Commission n.d) A step in the right direction may be the implementation of modern and efficient technologies in the work process of the majority of the MWWTPs and the recalculation and adjustment of the prices for treatment and recycling. Currently the problem lies mainly in the lack of funding for introducing newer technology on the Bulgarian market, but in addition to that, many of the MWWTPs operators are unwilling to undertake the tedious procedures of altering or obtaining permits necessary for the installation and operation of additional treatment units. Another drawback is the historical memory of the administration of the country. As a remnant of the socialist regime, conditions of higher difficulty have been maintained in the technical registration of plants, which is often more detailed than in the other EU Member States and has a more rigorous assessment and a more thorough examination of the technical parameters. (Expert working group 2021)

4.4 Sludge treatment methods in Bulgaria

The focus of the sludge treatment in Bulgaria mainly lays on processes of dewatering, drying, and different types of composting. The subsequent treatment and utilization of the useful nutrients present in the sludge are neglected or barely implemented on very few locations. The final sludge disposal is limited to agricultural utilization and landfill disposal – both techniques are discouraged to be implemented by some of the developed EU member states like the

Netherlands and Flanders (Lepez 2016). The main concerns are the accumulation of organic contaminants and the difficulties to monitor the usage. However, since 1986, there have been wide discussions between the EU member states on the impacts of the use of sewage sludge on land and nowadays the EU commission regulates that usage through heavy legislation, reporting, and evaluation. (European Commission n.d)

4.4.1 Thermal drying

Thermal drying is a process, in which the sludge is placed under high temperature for a fixed period of time. The temperature is not high enough to cause ignition, but enough to disinfect the sludge and prepare it for further treatment by improving its characteristics. The drying time is approximately 10-15 min and the solids' temperature should be kept between 60 to 93°C. (Climate policy watcher 2021) Newer technology for drying allow the sludge to be used as a fuel for the installation itself or for other units. Thermal drying can be highly cost-effective if renewable sources for drying are harnessed, e.g. sun radiation drying. Additionally, the dried product has increased content of DM, which, depending on other characteristics as well, makes it a substitute or addition to conventional fuels for the drying installation itself or other energy-demanding units. Should the sludge be pre-treated properly, it can be a great alternative fuel for electricity production power plants or cement producing factories. (Umweltbundesamt 2013)

To ensure high efficiency of the process, a combination of direct drying through convection, indirect drying through conduction and radiation drying is encouraged.

Most commonly, flash dryers, direct rotary dryers, and fluidized-bed dryers employ the convection drying method. In the convection driers, the sludge has a direct contact with the heat carrier, usually this is a hot gas injected into the dryer. (Climate policy watcher 2021) With the progress of drying, a mixture of water vapour, air, and hot gases is released. This gaseous mixture should be treated before being released into the atmosphere in order to prevent environmental damage. (Umweltbundesamt 2013)

On the other hand, horizontal paddle, hollow-flight or disk dryers, and vertical indirect dryers utilize the conduction method. The sludge is separated by the hot steam or oil by a metal wall. The heat is recirculated through the steam generator and is only transfered to the wet sludge through the heated metal surface. (Climate policy watcher 2021) This method if considered to be flexible in terms of inlet sludge, as it can treat both sludge with high and low water content and still release a homogenized substance as outflow. (Umweltbundesamt 2013)

Lastly, the radiation drying may be performed in a heated furnace or incineration plant, but it could also use sunlight as heat source. (Climate policy watcher 2021) It is a common method of thermal sludge drying because it requires few resources – enough room to scatter the sludge, sunlight, and little maintenance personnel. This method is more efficient if it is executed in a closed space with transparent ceiling, a greenhouse-like design, but could also be used in open space. However, there should be a storage space provided for the critical autumn-winter months. A major advantage of this method is the low energy consumption and the fact that it can act as improvement addition for other treatment techniques such as composting or even in energy recovery plants. The final substance obtained of this method is a soil-like one with up to 85% DM and low-to-none odour emissions. (Umweltbundesamt 2013)

According to a Report issued by the MOEW in 2011 most numerous type of pre-treatment unit in Bulgaria are outdoor drying beds using sun radiation. There were reported to be 375 such units on the premises of the MWWTPs in comparison to for example only 14 direct rotary driers. (MOEW 2011)

Generally, the process of drying may be divided into two groups:

- partial drying, where the DM content at the end of the process is between 60 and 80%;
- complete drying, where the DM content may reach up to 80-90%.

Partial drying is highly suitable when the following treatment is for example fluidized-bed drier or incinerator. The partial drying should be implemented only until the sludge has a positive contribution to the incineration energy balance. Complete drying is best implemented when the following treatment of the sludge includes combined incineration with solid municipal waste. Nevertheless, it can be also applied when the subsequent disposal method is agricultural utilization or composting. (Umweltbundesamt 2013)

4.4.2 Vermicomposting

Vermicomposting is niche of traditional aerobic composting. It is a process during which the organic matter from biodegradable waste, including sewer sludge, is decomposed with the aid of invertebrate organisms. One widely used organism is the Californian red worm (*Eisenia foetida*), which digests the organic matter and excretes as a product soil-like substance, called vermicompost, rich in nutrients and humus. (Castillo, Hernandez, Dominguez & Ojeda 2010)

The technology of vermicomposting differs from the conventional composting in a number of steps. It is important for the inlet material not to contain seeds or seedlings of weeds since the worms are unable to decompose them. (Grand n.d.) Usually in Bulgaria, sludge is mixed with other material like straw or residual greens from vegetation trimmings, which would result in the presence of seeds in the mixture. Therefore, conventional compost-like processes are let to occur to digest these seeds. The mixed piles are left outside, often mixed and closely monitored before the worms are fed into them. This method usually takes place outside in composting beds. (Expert working group 2021)

Once placed in the beds, there is no need for the mixture to be aerated since the organisms provide enough air. Depending on the chosen technology raw material could be continuously fed to the vermicomposting beds and the final product could be collected from the bottom of the beds, or each bed is left to decompose and convert into biohumus, and then it is collected. (Grand n.d.) The latter one is the more common method in Bulgaria. (Expert working group 2021)

The composting worms require specific environmental characteristics to survive and to process the raw material. The temperature in the vermicomposting beds should be between 15 to 30°C, moisture should be around 70% and the pH should be slightly acidic to neutral. (Grand n.d.)

In the course of 10 to 30 weeks, depending on the feed material and the preferred vermicomposting method, the efficiency of the process may result in up to 65% reduction of the total volume. To further speed up and make the process more efficient, it is advised to dewater the MWWTP sludge before adding it to the compost beds. Thus, the DM in the feed material will be increased, the amount of water that has to be evaporated is lowered significantly, and the optimal ratio between carbon (C) and nitrogen (N) will be achieved. (Umweltbundesamt 2013)

There are a few ways of organizing the composting beds – in open areas (in rows, as shown on Figure 6, or piles) and in closed systems. Usually controlling the parameters of the piles and rows is a more complicated process since they are highly dependent on the weather conditions. Apart from that, they require larger space and may cause problems with odours and/or leaching. (Umweltbundesamt 2013) However, being much cheaper than the closed systems, they are the preferred method by the operators of these units. (Expert working group 2021)

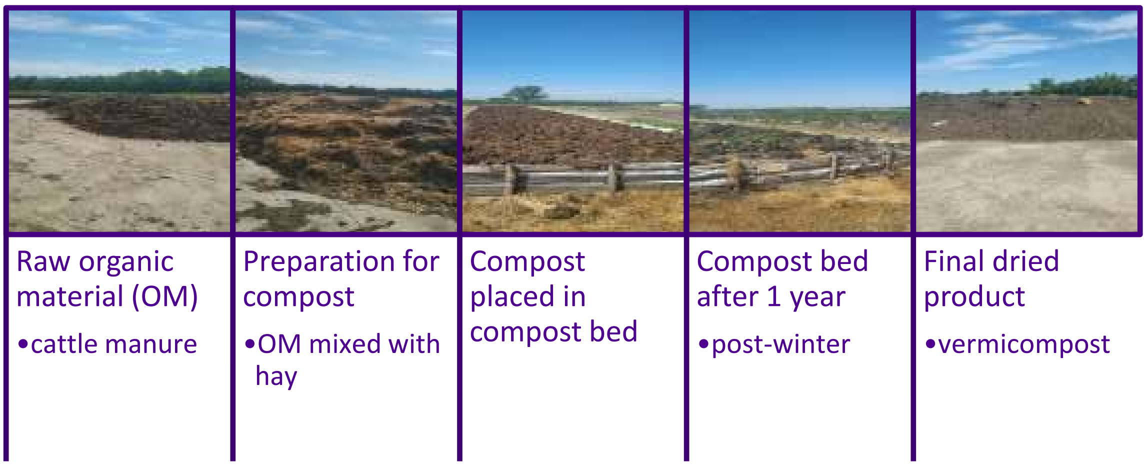

FIGURE 6. Vermicomposting process in pictures.

On the first picture in the figure is shown the raw material, mainly cattle manure provided by local livestock breeders and farm owners. This material has high moisture content and thus it has to be quickly mixed with dry materials like hay and straw (shown in the second picture). In such piles, the temperature rises enough to ensure the hygienization of the material. On the third one is seen the mixed material – the Californian red worm, sewer sludge, manure, hay, etc., placed in the compost bed. Important step for the proper vermicomposting is to aerate the mixture well in order to maintain the needs of the worms and the bio-chemical processes occurring. In the installation shown on the figure, the aeration is done manually through turning and gently mixing the material with shovels and rakes. The next picture is what the vermicompost looks like after at least 12 months. The OM is digested by the organisms and there is newly sprouted vegetation on top of the bed. In order to obtain the ready vermicompost material, as in the last picture, the compost is taken out of the bed and grinded in special machinery. After that process is executed, it is packaged and ready to be used as fertilizer.

The final vermicompost usually has higher concentration of nutrients due to the highly reduced volume. The presence of microorganisms is also preserved higher than in the conventional thermophilic compost since it is not treated at high temperatures, which are detrimental for the microorganisms. (Grand n.d.)

4.4.3 Utilization in agriculture

Currently utilizing sludge in agriculture is one of the most widely spread methods of repurposing MWWTP sludge in Bulgaria. Partially this is such a common method because the largest sludge generating plant – Sofia MWWTP, has a long-term contract with agricultural producers to use the sludge. Being situated near the capital city and serving the most populous city in the country, the inflow of wastewater, and respectively the outflow of sludge, is highest in Bulgaria. (NSPST 2014) However, the distribution of sludge utilization around the country is uneven due to various reasons. One of the most important is the tedious legislative laboratory procedure that has to be fulfilled in order to obtain a permit to use it as soil improver or fertilizer. Laboratory analyses have to be executed to ensure there are no hazardous substances or heavy metals, or substances that may cause health problems.

Some EU member states like the Free State of Bavaria in Germany and parts of Austria (Milieu Ltd et. al 2010) have limited the usage of sludge in agriculture as in many cases the different sludge batches have disparate characteristics and it is impractical to analyse them constantly. (Umweltbundesamt 2013) However, these examples are opposing to the common practices. Spreading sludge on land is a common disposal method in many EU member states. Therefore, it can be concluded that the utilization in agriculture is dependent on the local and national-level decision makers and legislation. (European commission 2021)

Utilizing sludge in agricultural or disturbed land improving, is highly legislation and weather dependent. According to the current legislation in Bulgaria, this method can be performed only during certain months of the year and under specific meteorological conditions – low precipitation, absence of rain, moderate temperature, etc. These factors presuppose that the pre-treated sludge has to be transported and temporarily stored in assigned for the purpose units. In Bulgaria, such units are most often outdoor spaces. Preserving the sludge there is highly inefficient since its characteristics are being changed as time passes, the water content increases and thus the pre-drying or dewatering is senseless. (Umweltbundesamt 2013)

Additionally, the open area storage provides suitable conditions for the formation and development of microorganisms, or the appearance of airborne spores or pathogens. Storage space is available usually on-site of MWWTPs, but not on all of them. Therefore, transportation of the sludge from one plant to another is required. An inevitable problem here is the volume of the sludge, which if not pre-dried or dewatered consists mainly of water that has to be returned into a WWTP. This makes the transportation costs extremely high and not repayable. (Umweltbundesamt 2013)

It is important to be noted that this method is viable only when used in combination with other pre-treatment methods like drying, composting or anaerobic digestion.

4.4.4 Landfill disposal

Landfill disposal is the least encouraged method of sludge disposal, and yet it is still applied in Bulgaria. For the conduction of the NSPST (2014), different research had been conducted but the results obtained were not satisfactory. According to the authors of the Plan, the different governmental agencies provide contradicting information that is not consistent throughout the years of the conducted research. However, the gathered data there suggest that although slowly, the landfilled sludge amounts are decreasing form 2004 to present-days.

Often the landfill facilities for sludge are separate ones from the municipal solid waste (MSW) landfills. They are either too expensive to build and later on to maintain in proper shape or they are already too old, outdated, and do not meet the current legislative criteria. Although it is advised to have separate landfills for the sludge, it is possible to spread them on a MSW landfill upon mixing them with clay and using them for daily cultivation of landfills. A combination of the mentioned practices may hide potential risks to the surrounding environment of the landfill. Often leaching, odours, microorganism development, etc. are not monitored and hardly can they be prevented. In addition to the potential risks, the useful organic nutrients of the sludge are wasted. (Indzhova 2021)

According to *Council Directive 1999/31/EC of 26 April 1999 on the landfill of waste*, the landfilling of sludge should be no different from other waste. This would mean that the sludge should be treated. The definition of “Treatment” according to the Directive is “the physical, thermal, chemical or biological processes, including sorting, that change the characteristics of the waste in order to reduce its volume or hazardous nature, facilitate its handling or enhance recovery”. Upon deposition of the sludge on the landfill, it should be adequately monitored and managed to prevent or as a bare minimum reduce potential adverse effects on the environment and risks to human health. (Council Directive 1999/31/EC) Unfortunately, a large number of the landfills in Bulgaria have been constructed a long time ago and they do not meet the current safety criteria, there is very little possibility to monitor them, and their structure is not suitable for receiving and storing sludge.

On the other hand, this method is also not compatible with the Waste management hierarchy (Figure 1), in which the landfilling is positioned as the lowermost step that should be avoided. An important factor for the ongoing wide practice of landfilling is the financial side of the problem. Although the fare for such disposal has been consistently increased in the last years, this method remains one of the cheapest ones and thus makes other possibilities unalluring to the owners of the waste.

Furthermore, as there are not available disposal units near most of the MWWTPs, the operators are forced to seek other methods, the most easily accessible and least monitored one being landfilling. The transportation of the sludge to other disposal sites is expensive and requires a long process of organizing a contract with transportation company, analysis of the sludge in order to be accepted in the disposal unit, notifying authorities, and other important but tedious obligations that can be avoided if the sludge is disposed on a landfill. The government is working on altering this practice, but the shift is time consuming and requires change in the mindset and understanding of the MWWTPs operators.

4.5 European practices in sludge treatment

4.5.1 Anaerobic digestion – converting biomass into energy and compost

Anaerobic digestion is a complicated process, which requires close monitoring and maintenance of heavy anaerobic conditions. Since the decomposition of the organic matter is done by microorganisms, suitable living conditions have to be provided. The very basic work principle of the process is as follows – during the first phase, hydrolysis, the insoluble organic materials are converted to soluble acids. During the next step, these acids undergo fermentation caused by bacteria where gases like ammonia and sulphuric acid are formed. In the last stage, the previously formed products, together with the remaining acids and alcohols, are further digested by methanogenic bacteria and as a result, methane is produced. (Appels, Baeyens, Degreve, Dewil 2008)

Various parameters have to be monitored during the occurrence of the processes. The ones that have greatest effect are the pH, alkalinity and the temperature. These are the catalysts and the predispositions of an effective digestion. (Appels et. al 2008)

4.5.2 Incineration – combustion of sludge, co-incineration with MSW

Incineration of municipal sewer sludge can be applied in the form of combustion, usually used as synonyms, or co-incineration with MSW. In this thesis, the term “Incineration” is used as general inclusive term of the sludge-only combustion and co-incineration of sludge and MSW. In the near past, this technique has undergone major development, both in the spheres of machineries and of legislation. These changes have led to the lowering of air emissions and improvement of the efficiency and final products, together with lowering the costs for incineration, and the waste streams. The main aim of incineration is to regenerate the energy from the waste while minimizing the solid output waste and the aerosol emissions. Incineration can be described as the process of oxidizing the combustible hydrocarbon compounds present in the waste, and obtain as products CO_2 and water vapour. This process is undergone at temperatures between 400 and 1000°C, most commonly between 850-950°C. (Samolaada, Zabaniotou 2014)

Since the overall enthalpy change is negative, the reaction is considered exothermic. (Angelova, Kioseva & Dombalov 2014) As the released energy is in the form of heat, it is a great addition to local central heating or substitute energy for drying of the sludge. The other output materials include the inorganic materials in the form of ash. This ash may also be introduced as an addition material to some manufacturing industries like cement or ceramics production. (Expert working group 2021)

The incineration of sludge is among the most popular disposal methods in Europe. Many of the industrialized countries rely on this technique as a substitute to landfilling and utilization in agriculture, both of which holding many limitations as discussed in the previous chapter. The variety and scope of available installations for incineration and the rapid development of the method, guarantee its leading positions in the future. (Samolaada, Zabaniotou 2014)

A major problem in these plants occurs from the low caloricity of the sludge, which is much lower than the one of coal, and thus the output of heat is lower. For the cement industry sludge can be a sustainable additive material to their product. A drawback is the high requirements for the ash formed by the combustion of sludge. The ash often has high content of heavy metals, toxins, and inorganic substances. Should such material be included in the composition of the cement, its quality is largely diminished and its cost is not market-competitive.

4.5.3 Pyrolysis

The process of pyrolysis involves heating of any biomass, including sewer sludge, in anaerobic conditions at high temperature and keeping the mass at that temperature for a few minutes, enough to produce noncondensable gases, solid char, and another liquid product. (Basu 2013)

The basic principle of the process goes as follows: the biomass is fed into a pyrolysis chamber, where it is heated to the *pyrolysis temperature* (~300-650°C). The recommended treatment time is between 30 and 60 min. However, research has shown that shorter periods of about 5 minutes can be as effective as the 60 min in terms of pollutants removal. This is the beginning of the decomposition of the biomass. When it has remained in the chamber long enough, condensable gases are released and leave the chamber while the solid char remains partly in the chamber and partly in the gases. It is separated from the gas by cooling it down, while from the condensable vapour pyrolysis oil is formed. The noncondensable gases produced during the process are carbon oxide, carbon dioxide, hydrogen gas, and methane. Of highest interest for the operators of these units are the noncondensable gases since they can be used as energy source or can even be recycled in the process as heating source. Similarly, the biochar can find various commercial uses or it can be further burnt to produce more heat for the pyrolysis process. There are various pyrolysis methods depending on the temperature, time and the sought final products. (Basu 2013)

Although the pyrolysis technique is still a niche, it is well known around Europe with dozens of plants operating commercially or privately. There are various funding institutions supporting the development of the technology. However, such plant does not exist in Bulgaria even on pilot scale.

5 DISCUSSION AND CONCLUSION

As seen from the analysis in Chapter 4.4, the most common practices in Bulgaria are the drying of sludge and its agricultural utilization. This is also confirmed by Mrs. Indzhova, who states that the thermal drying is suitable technique given the local differences regarding the generated quantities of sludge and the sludge characteristics.

However, she raises the important question of what happens next with the dried sludge. Thermal drying has become highly efficient in the last years. Some newer units can reach DM content of ~90% in comparison with commonly used older ones, which increase the DM content to about 65%. Through her experience, she has concluded that without further utilization – treatment until obtaining waste or product material, even this method would not be efficient enough on its own.

Therefore, a comparison between the European treatment good practices is executed and presented in Table 1 in order to determine which one is the most suitable to be introduced in Bulgaria. The comparison is based on different sustainability and SWOT-analysis-based criteria – DM contents, costs, output materials, advantages, disadvantages, and opportunities.

5.1 Advantages and disadvantages of anaerobic digestion

Anaerobic digestion can be well implemented in the sludge treatment in Bulgaria if digesters are installed on the premises of bigger MWWTPs. This would lower the transportation costs. A problem here is that the big producers of sludge already have figured disposal methods and are not highly likely to be willing to change them. One opportunity for this technique are the other organic materials such as food industry waste or grease trap sludge, which are eligible as inflow to the digesters, and the quality of the produced methane can be improved. Depending on the in-flow materials, the methane content in the outflow can be as high as 60-70% and CO_2 – 30-40%. This makes it suitable for direct use as vehicle fuel or for generation of heat or electrical energy (Executive Environment Agency 2017). This will not only increase the profits but will act as a waste disposal solution to other industries and in the long turn it may lower the environmental strain of using fossil-based fuels by replacing them with this alternatively-produced methane.

Unfortunately, techniques like thermal drying and anaerobic digestion, however efficient and widely spread, are not capable to fully remove commonly found pathogens in the sludge. Even upon treatment through these techniques, many of the substances found in personal care products, pharmaceuticals, and other toxic substances remain in the sludge and cause potential risk of crops contamination if the sludge is further utilized in agriculture. (Buss 2021)

A rising problem with the utilization of anaerobic digestion gas is the presence of silicones or silicon-containing compounds, which are added to personal care products, detergents, etc., and end up in the wastewater streams, consecutively in the MWWTPs' sludge. As they cannot be digested, they eventually end up in the biogas. Upon burning of the biogas, they are converted into hard, crystalized silica, which deposits on the gas beneficiation unit. This may lead to crystals accumulating in the lubrication oil, malfunction of the equipment, and costly reparations. (Appels, et. al 2008) Another toxic substance that is commonly found in the produced biogas are the hydrogen cyanides (HCN), originating from the nitrogen-containing substances. The HCNs are used in the production of nylons and plastics, and they may cause similar troubles like the silicones. (Umweltbundesamt 2013)

On the other hand, this method could replace partly the composting of high-moisture organic waste, which tend to be much harder, time and energy consuming to compost. A drawback would be that the energy balance is hard to maintain if there is not enough feeding material. In addition, the initial funding of building commercial scale digesters and the following exploitation costs can be high. (Umweltbundesamt 2013)

The anaerobic digestion is a treatment method of organic waste that has majorly spread throughout Europe in the last 25 years. According to a fact sheet published by European bioplastics c.V. (2015) in 1990 there were only three plants in Europe with total capacity of 120 000 tonnes/y, while in 2015 these numbers grew to 290 plants with total capacity of over 9 million tonnes/y. This method is preferred by many countries nowadays as it effectively reduces the amounts of biodegradable waste, including the sewer sludge, while it produces useful side streams such as “green” energy and residual biomass in the form of compost. (European bioplastics c.V 2015)

In Bulgaria as of 2017, there were only four such installations. (Executive Environment Agency 2019). Usually the produced methane is transformed into heat and electricity and it is supplied to the central grid operators. The produced power is almost never used for the own need of the units as it is not as monetary viable as selling it and then rebuying from the grid operator. (Executive Environment Agency 2017)

5.2 Advantages and disadvantages of incineration

Despite the high public opposition towards incineration of waste (Samolaada, Zabaniotou 2014), it is one of the most widely spread practices in Europe. In Table 1 is seen that incineration of sludge has the disadvantages prevailing over the advantages. The benefits with this technology are that the energy potential of the sludge is utilized and all the pathogens are removed. However, there is still the limitation of the residual ash. Although that waste ash can be used as raw material for other industries, the requirements towards it are highly strict and the decision of whether to include it in the process is made by the plant operators. Even in case this method is more widely introduced, the monitoring of the inflowing material should be high. Such installations require high DM content, and lack of pollutants such as halogens and heavy metals. (Executive Environment Agency 2017) Given the experience with low control and poor reporting of information, this monitoring of the inflow sludge does not seem to be easily achieved in Bulgaria.

On the other hand, should proper control and monitoring be provided, the costs of the exploitation of such plants are admissible. Most of the types of incineration plants require high initial costs in order to be emerged, but their after maintenance is relatively low. The technical maintenance, the unit’s upkeep, and personnel-related costs are minimal in comparison with the other thermal treatment technologies. (Umweltbundesamt 2013)

A comparative analysis study (2014) reports that the average amount incinerated sludge in EU27 for 2010 is 27% with the majority of the northern European countries reaching above 30%, while the central and eastern European countries remaining between 0 and 5%. For Bulgaria, the percentage for 2010 was 0%, with predictions to raise up to 35% by 2020 (NSPST 2014).

Currently there are no sludge-only combustion facilities in Bulgaria. Therefore, the percentage of incineration of sludge, which is much lower than the prediction, is achieved only through co-incineration with MSW. (Expert working group 2021) Sewer sludge is only co-incinerated in thermal power plants (TPP) and some cement production plants. There are three cement plants that hold an environmental permit to incinerate sludge, one TPP holding a permit, and three private mixed-waste incineration plants (Public register of Environmental permits n.d). Interestingly, most of these units are located in the northern part of Bulgaria, where the MWWTPs and the amounts of sludge are much lower in comparison with the southern territories.

5.3 Advantages and disadvantages of pyrolysis

Although pyrolysis is the most complex process among the ones explained in Chapter 4.5, it is a promising treatment technique due to its various advantages and high efficiency. The pyrolysis temperature is typically lower than the temperature required for incineration, which makes the process slightly easier to carry out and with lower energy demand. However, some of the constraints of pyrolysis include the maintenance of high-pressure chamber and the high price of the produced fuel. On the other hand, during pyrolysis many concerning substances such as pharmaceuticals, antibiotic resistance bacteria, microplastics, and other organic compounds can be efficiently removed. (Basu 2013) Kimbell et al. (2018) report that pyrolysis at slightly higher temperature than the averagely used one can reduce the presence of some antibacterial pharmaceuticals, as well as the highly toxic PCBs up to 99%. The remaining percentage is low enough to be undetectable in the remaining biochar. Similarly, this process is beneficial in the removal of microplastics found in the wastewater as well. The concentration of the microplastics, commonly present in cosmetics and health care products, can be reduced by more than 99% when exposed to pyrolysis temperature. In addition, the remaining low concentration of microplastics in the biochar is undetectable and thus its further uses are extended. (Basu 2013) A major plus is this technique is the lack of waste outflow (Table 1). All the output materials are suitable for further utilization and can provide financial benefits for the operator and minimize the environmental impacts resulting from the sludge management. As a relatively new technology, there is wide room for improvement and optimization, making this process attractive for investors, entrepreneurs, and WWTPs operators.

TABLE 1. Comparison between the post-treatment techniques (Appels et. al 2008; European bioplastics c.V 2015; Samolaada, Zabaniotou 2014; Angelova et. al 2014; Expert working group 2021; Basu 2013; Umweltbundesamt 2013)

Evaluation criteria	Anaerobic digestion	Incineration	Pyrolysis
DM of inflow material [%]	30-45	41-65	25-35
Costs	High initial and maintenance costs	High operation costs due to need of additional abatement equipment	High initial investment
Output materials	• Methane; • Biomass in the form of compost.	• Heat; • Residual ash.	• Solid biochar; • Liquid pyrolysis oil; • Pyrolysis gases.
Heating values	Of methane – 18-28 MJ/Nm^3	• Of raw sludge – 11-17MJ/kg; • Of MSW and sludge – 11-22MJ/kg.	• Of char – 5MJ/kg; • Of liquid – 13-15MJ/kg; • Of gas – 11-20MJ/Nm^3.
Waste	None	10-30% of the input material;	None
Drawbacks	• Partial decomposition of the organics; • Many indicators should be monitored;	• Public opposition; • ~30%/inflow sludge remains as ash;	• Lacking product standardization; • Lack of Best Available Techniques;

Evaluation criteria	Anaerobic digestion	Incineration	Pyrolysis
	• Potential presence of silicones in the gas; • In biogas HCN may be present; • Biogas needs to be compressed before storage; • Heavy metals concentration is increased in the residual compost.	• Potentially classified as hazardous waste; • Additional expenses of waste handling; • Low energy efficiency; • High GHG emissions; • Requires maintenance of high temperature at all times; • Alternative fuel price is not market competitive.	• Costly operation unit.
Advantages	• Volume is reduced; • Most pathogens are destroyed; • Odour emissions are limited; • The biogas has high heating value;	• Reduction of volume; • Removal or pathogens; • Odour minimization; • Energy recovery.	• Non-burning process; • Useful output materials; • Conversion of all sludge biomass; • Compression of volume of the inflow material;

Evaluation criteria	Anaerobic digestion	Incineration	Pyrolysis
	• High yield of biogas annually; • Highly efficient energy recovery method.		• Minimal to none GHG emissions • Phosphorous regeneration from the biochar.
Opportunities	• It is encouraged and widespread in Europe; • Room for development and optimization; • Can be used as preceding process for pyrolysis.	• Implementing ash as side stream; • Improvement of air emissions abatement equipment; • Co-incineration with coal/lignite in order to improve energy quality; • Waste utilization in cement manufacturing plants.	• Wide market for output materials; • Raw material is plentiful.

The increasing concentrations of various toxic substances in the municipal wastewater, subsequently in the sewer sludge, require more thorough treatment and techniques capable of lowering these concentrations. Although the municipal sludge, taken into account in this thesis, is not classified as hazardous, it can still exert major environmental strain if not treated right. To minimize the impact and to maximize the benefits, a combination of the afore-tackled techniques would be the most suitable coping mechanism.

5.4 Suggestion for improvement of the Bulgarian model

As a result from the conducted research and the established analysis, it can be concluded that in the best-case scenario pyrolysis would be the most suitable treatment technique for Bulgaria out of the European good practices. This opinion is also endorsed by Mrs. Indzhova, who considers this technique to be overtaking the waste treatment market in the near future. Although the necessity of dewatering or even drying of the inflow sludge is perceived as a weakness, this is already a wide practice in Bulgaria, therefore this step can be easily supplied. Despite the not very well established market of the output materials, they offer great opportunities for development of the alternative fuels market niche. However, the lack of funding and the high initial investment costs for the process would set aside this technique.

The more easily applicable solution with minimal costs and changes to the current situation in the country would be to improve the already existing facilities. Optimizing the anaerobic digesters' work, collecting the methane and other GHGs released during the initial steps of vermicomposting, and improving the control over the dispersion of sludge on agricultural lands, as well as the overall control on sludge management, would be the initial steps to solving the constantly growing problem with sludge quantities and its treatment. The improving of existing treating facilities is much cheaper and accessible option for Bulgaria. Best-fit solution, apart from the introduction of completely new technology, would be the modernization and wider use of the anaerobic digesters. There are already established good practices and wide European experience making the refining of this method less complex and more cost effective. Out of the methods described in Chapter 4.5, this one remains the cheapest and least complicated in terms of upkeep and operation. In addition, the resolving of the identified problems in Chapter 4.3.3 would positively affect the sludge management process.

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APPENDICES

Appendix 1. Interview with waste management expert Nedka Indzhova

Interviewee:
My name is Nedka Indzhova. I'm an Ecologists. I have a Master's degree of Plovdiv university in the field of Ecology and I have been working in Eco Resolve for nearly 12 years. I am responsible for the consultation waste management and waste treatment. I have to communicate with many and different clients from different business spheres in Bulgaria. I like my job, of course. I have interests in the field of waste management, and I have been involved in projects in project, which has to discuss and show the ways of the waste treatment of sludge in Bulgaria generated by wastewater treatment plants. The project was very interesting. We had to research the ways of sludge treatment in Bulgaria at this moment. We did that, of course, with my colleagues.

Genuinely I can say that the treatment of waste sludge in Bulgaria has many opportunities. It is good that today, in this moment, Bulgaria can choose the different ways to treat this waste according to the regional differences, financial costs, the best available techniques in Europe at this moment, et cetera.

I think that the future of waste sludge treatment is a combination of some technologies. The most important of which is maybe pyrolysis. Also drying the sludge allows decreasing the water content at the exit of the installation. We can have sludge with only 10% water content. This is very good for the following treatment of the sludge. As a result of drying the sludge can change into organic soil improver or another product for soil enrichment. Of course only if it meets the requirement of the specific legislation.

Interviewer:
So do you think this is the most common practice for treating sludge in Bulgaria – drying the sludge?

Interviewee:

Yes. I think that is a good and suitable technic for the current situation in Bulgaria. Taking into account the local differences, I think that the best solution is a combination of some treatment methods.

Interviewer:
I see. And on European scale, which one of the techniques do you think is the most effective or efficient?

Interviewee:
Oh, I think according to the waste treatment hierarchy turbo drying is the best technique. And it meets the requirements of the European legislation. That is a good way of pre-treatment and a sustainable decision for sludge treatment in Bulgaria.

Interviewer:
And now, having explained the current situation, how do you see the development of this field in the future in Bulgaria? Do you think that authorities should be more involved?

Interviewee:
And yes, I think because the problem with the sludge will increase because of increasing use of water and emerging of new WWTPs. And in the near future we need to introduce sustainable waste management techniques.

Interviewer:
Well, thank you very much for that introduction about the situation in Bulgaria and for the time spent with me.

Interviewee:
You are welcome any time.

Appendix 2. Generated sludge quantities by municipal district in 2018

This data is according to the Executive Environment Agency 2019 report.

№	***Municipal disctrict***	***Amount of sludge [t/DM]***	**№**	***Municipal disctrict***	***Amount of sludge [t/DM]***
1.	Blagoevgrad	777,95	9.	Plovidv	4 810,00
2.	Burgas	3 319,94	10.	Ruse	6 614,46
3.	Varna	2 899,32	11.	Smolyan	209,08
4.	V. Tarnovo	1 499,68	12.	Sofia	23 101,00
5.	Vratsa	606,53	13.	Stara Zagora	2 061,40
6.	Montana	356,54	14.	Haskovo	2 810,36
7.	Pazardzhik	841,26	15.	Shumen	876,22
8.	Pleven	1 996,02	16.	Pernik	240,59