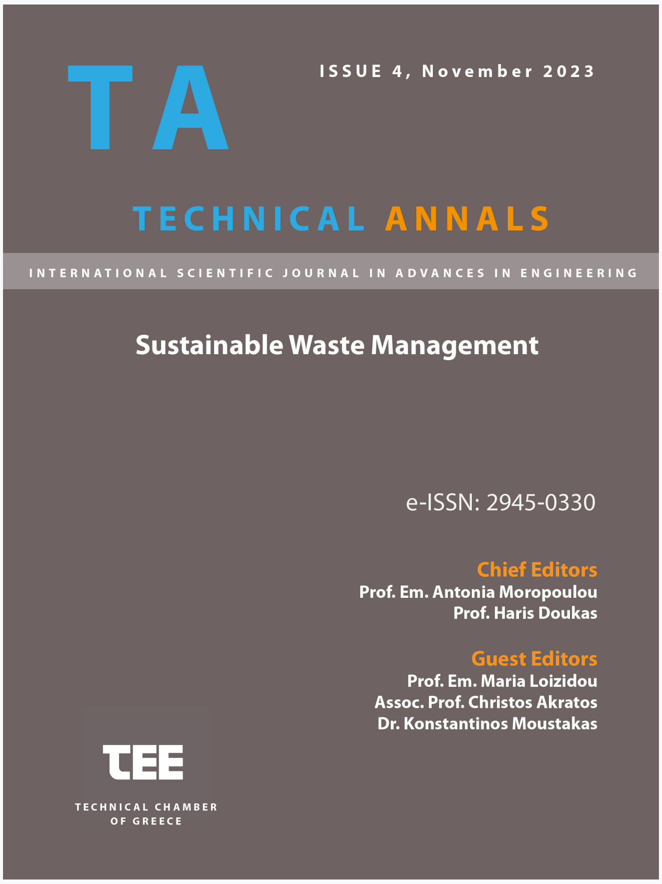
Technical Annals

Vol 1, No 4 (2023)

Technical Annals



A Review of contemporary sewage sludge treatment and management methods in European countries with an emphasis on Greece

Aikaterini Eleftheriadou, Christos Akratos, Athanasios Vavatsikos, Maria Evridiki Gratziou

doi: 10.12681/ta.36997

A review of contemporary sewage sludge treatment and management methods in European countries with an emphasis on Greece

Eleftheriadou A.[1], Akratos Ch.S.[1], Vavatsikos A.[2], Gratziou M.[1]

[1]Department of Civil Engineering, Democritus University of Thrace, Building B, Campus Kimmeria, Xanthi, 67100
[2]Department of Production and Management Engineering, Democritus University of Thrace, 12 Vas. Sofias st., Building I, Xanthi, 67100
aielefth@civil.duth.gr

Abstract. Municipal sewage sludge is an acute problem in both developed and developing countries. Researchers are conducting many experiments to solve this problem. There are many methods of disposal, neutralization, or reuse of sediments after neutralization. The review of contemporary sewage sludge treatment and management methods in European countries with an emphasis on Greece will provide more information about the most appropriate choice for the use of sewage sludge in Greece.
The challenges linked to aligning sewage sludge management with the principles of sustainable development are examined. The article references information sourced from the publication in Official Gazette 2692/B/21-04-2023, alongside ongoing projects in Greece concerning sludge treatment within Urban Wastewater Treatment Units. Furthermore, it delves into the projections and strategies for sewage sludge processing in Greece, by analyzing the obligations and projections outlined in the National Waste Management Plan 2015, juxtaposed with the revised National Waste Management Plan of 2020.
In Greece, following the initiation of the "Treatment and purification of urban wastewater in environmentally sensitive settlements and modernization of facilities" project under the Recovery and Resilience Fund from 17/01/2023, there is a noticeable shift towards thermal treatment of sludge utilizing drying methods (including solar, etc.). By 2025, this trend is expected to significantly alter the landscape of treated sludge disposal in Greece. However, addressing the management of sludge generated by municipal urban waste treatment units and selecting the most suitable strategy for urban sewage sludge management continues to pose a complex challenge.

Keywords: Wastewater treatment plants (WWTPs); Sewage Sludge; Management.

1 Introduction

Rapid population growth, climate change, urbanization and depletion of natural resources compel global society to prepare to be disadvantaged with respect to certain natural resources [1]. Other approaches to resource utilisation, such as the recycling of waste, particularly sewage sludge, offer potential solutions to mitigate this problem [2]. In line with this, the National Waste Management Plan [3] (ESDA, 2020) proposes that sewage sludge effluent should be recognised as a valuable resource rather than simply categorised as waste. Shaddel et al [2] state that wastewater contains nutrients, need research for food production, and that wastewater and sludge have been explored in the last decade for nutrient recovery. Shaddel et al [2] have however warned that the sludge may contain hazardous organic and inorganic contaminants. After its publication with the Official Gazette 2692/B/2023/21-04-2023 we notice that the environmental legislation in Greece, regarding the disposal of sludge, is being increasingly tightened. With the aforementioned ministerial decision (Ministry of Environment and Energy/ Official Gazette /41 828/630/21-04-2023) [4] strict restrictions and continuous controls are set for the correct use of treated sludge in agriculture, the calculation and other parameters such as conventional fertilization, and above all the control of the quality of the sludge and the care to avoid possible failure and non-compliance with the study of the sludge in each area. One of the primary objectives of municipal or industrial wastewater treatment plants is to attain the maximum possible removal of solids with the highest possible degree of solid concentration. To achieve this goal, a range of technological processes are employed, including sedimentation processes (commonly utilized in both water and wastewater treatment) [5], as well as mechanical thickening. The characteristics of sewage sludge largely hinge on the technology deployed at the sludge treatment facility [6], as well as the nature of the sewage itself (whether municipal or industrial).

According to Christodoulou and Stamatelatou [7], sewage sludge is considered as a source of renewable energy and material recovery, not as 'waste' but as a by-product to be processed for recycling.

The volume of sewage sludge has been increasing sharply in the past decate due to the unprecedented rate of industrialization and population growth [8]. Consequently, the management of sewage sludge in an economically and environmentally acceptable manner has become one of the most serious problems facing society today. Therefore, the operation of Wastewater Treatment Plants faces a new challenge regarding sustainable wastewater management, revealing a major new environmental issue in the management and long-term disposal of sewage sludge. The volume of wastewater and how it's treated varies according to a country's level of economic development. Managing sewage sludge from wastewater treatment plants (WWTPs), including processing and disposal in landfills, is a significant concern in wastewater management. Sewage sludge harbors a range of harmful pollutants that pose risks to both human health and the environment, emphasizing the importance of proper treatment and utilization [9,10,11].

The reuse of sewage sludge for the aforementioned purposes is economically viable and environmentally friendly compared to handling it as waste and disposing of it in local landfills, as was implemented for 98.50% of the produced sludge in 1998 and still at 38.5% in 2020 in Greece [12].

Therefore, it is understood that potential improvements in environmental protection are to be achieved through solutions already implemented in the European region and have been successfully applied, disposing of only 4.50% of the total produced sludge in landfills in 2020, as in the case of Finland (43.50% disposal in Agriculture, 47.30%

composting, 3.7% thermal methods, and 0.70% other methods). Examining the current European reality forms the basis for a broader examination of the prevailing Greek legislation as shaped by recent laws which define the future of sludge management in Greece until 2030, essentially revealing to us the practical framework for implementing regulatory measures for sludge [3].

2 Legislative Overview of Sewage Sludge in Greece

The legal regulations in Greece regarding waste management are adapted to European legislation, specifically the Directives 86/278/EEC - Sludge Directive, concerning the limitation of composting and agricultural use of waste. Directive 99/31/EC for the limitation of disposal, Directive 2000/60/EC which establishes the rules for a common community action in the field of water policy, where sludge is defined not as waste, but as a product from the wastewater treatment process. Also, Directive 2000/76/EC which set the rules for the non-restriction of incineration and co-incineration as a method of managing wastewater treatment sludge. Additionally, Directive 91/271/EEC included guidelines for limiting the impacts from the increase of sludge mass, disposal processes, or treatment or decomposition of stored plant and animal residues.

Specifically, in Greece, in 2012, the Special Service for the Management of the Operational Program "Environment and Sustainable Development" (Ministry of Transport and Environment) 2007-2013 issued a call titled "Projects for the management and safe disposal of sludge" to the relevant bodies of the country ((MWSSC): Municipal Water Supply & Sewerage Company, Municipalities, etc.) for the submission of proposals to be financed by the NSRF. This call provided for the "implementation of sludge management and safe disposal projects aimed at the drastic reduction of sludge pathogens (sanitation) and/or the drastic increase in solid content, to make its subsequent disposal and overall utilization safer and with greater options." Although there was a response from the agencies, as evidenced by the submitted proposals, no relevant project was included for funding in the Program, and the process was interrupted, as the institutional definition of "sludge sanitation" could not be established, and the issuance of the relevant Joint Ministerial Decision was not finalized.

The Greek Government sought the support of the European Commission in specific areas (such as, among others, the improvement of urban waste management, regulatory issues in the waste sector, and the management of specific waste categories) with the aim of increasing the quality and quantity of recycling, improving the quality of data, and effectively using economic tools. To achieve the aforementioned goals, the Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH (GIZ) provides "Technical support for the implementation of Greece's National Waste Management Plan (NWMP)" from 2018 to 2021. The project is funded by the European Union (EU) through the Structural Reform Support Program (SRSP), and the German Federal Ministry for the Environment, Nature Conservation, and Nuclear Safety (BMU) and is implemented by GIZ and the Greek Ministry of Environment and Energy (YPE), in collaboration with the European Commission.

Furthermore, a technical report on the criteria for imposing a waste fee for biodegradable waste subject to biological treatment has categorized sewage sludge as a waste included in the positive list. Recently in Greece the interpretive circular was issued from 12-20-2021 pursuant to article 38 of Law 4819/2021 - Burial fee, in which it is stated that the competent bodies that have not included the burial fee in their pricing policy and budget, must promptly comply by revising their budget and pricing policy, while informing the General Secretariat of Waste Management Coordination. Greece, as a member state of the European Union, must attune its national legislation to the legislation of the European Union. The result of these actions is JMD (Joint Ministerial Decision) 80568/4225/1991 as replaced by the ministerial decision of 04-21-2023 (Government Gazette 2692/B/21-04-2023) [4] for the use of waste sludge in agriculture (in application of Directive 86/278/EEC, JMD 29407/3508/2002: Measures and conditions for the sanitary landfill of waste (Government Gazette 1572/02) which incorporated into our national law Directive 99/31/EC as was replaced by Official Gazette 2692/B/2023/21-04-2023, in which strict restrictions and continuous controls are set for the correct use of treated sludge in agriculture, JMD 22912/1117/2005: Measures and conditions for the prevention and limitation of environmental pollution from the incineration of waste, to incorporate Directive 2000/76/EC, Law N.4014/2011: Environmental licensing of projects and activities, regulation of arbitrary in connection with the creation of an environmental balance and others provisions of the competence of the Ministry of the Environment, as amended and in force (Article 12, Licensing for the operation of a landfill) (Government Gazette 209/A/21-9-2011), the law N.4042/2012: Criminal Protection of the Environment – Harmonization with the 2008 directive /99/EC – production and waste management framework – Harmonization with directive 2008/98/EC – Regulation of Ministry of Environment, Energy and Climate Change matters (Government Gazette 24/A/13-2-2012) and the JMD 51373/4684/2015 [13] which validates the National Waste Management Plan and the National Strategic Prevention Plan. With the latest joint ministerial decision, the following goals were set for sludge:

- Minimizing the disposal of the sludge in Sanitary Landfills.
- Sludge recovery, 90% by weight of the produced quantity. The Disposal of the sludge must be less than 10% by weight of the produced quantity, by 2030.
- Development of an infrastructure network for the recovery of sludge produced by the treatment of municipal wastewater.
- Information regarding the possibilities of proper sludge management for sludge producers.

In conclusion, studying the above legislation, the following alternatives can be distinguished through which, in general, the sludge from WWTPs can be utilized according to the Greek Legislation.

- By using the sludge in agriculture, either directly or after processing, always respecting the restrictions and specifications those have been set, in accordance with the respective legislation.
- By using the sludge after drying, as a fuel, in industry and in thermal power plants.
- By using the sludge after dehydration, in the biogas production units.

- By using the sludge in landscape restoration after sanitation, stabilization and drying.

The introduction of these legal regulations has differentiated the consideration of disposal in the management of sewage sludge before and after 12.31.2021, the date of application of the burial fee to the existing landfills of the Greek area and has troubled the municipal units for the treatment of urban waste regarding the ways of managing it.

Specifically, in Greece, in May 2022, the updated National Operational Plan for Wastewater was formulated, including the summary table of necessary funding for the proposed measures/actions (Table 8 of the Operational Plan) to ensure the country's compliance with Directive 91/271/EEC. The total cost of the necessary measures/actions (studies – expert opinions, construction of new WWTPs, improvement of operation and upgrading of WWTP infrastructure, sludge utilization projects, and effluent reuse projects) is estimated at €2,322,487,464 (excluding VAT).

Additionally, in August 2020, according to the Special Service for the Management of the Operational Program "Transport Infrastructure, Environment & Sustainable Development" 2014 – 2020 (Ministry of Transport and Environment), an inventory was made of the sludge management projects planned by 38 (MWSSC) Municipal Water Supply & Sewerage Company in the country, with a total indicative budget of €137 million. These proposed interventions include the construction of projects and the procurement of equipment for the implementation of mainly conventional methods of sludge treatment and management (drying, dewatering, composting, etc.), with few exceptions where alternative sludge management and utilization solutions are planned from WWTPs (e.g., Volos, Kalymnos, Zakynthos), as well as combined solutions for the management of sludge together with the organic fraction (biowaste) of municipal solid waste (e.g., Skiathos, Rethymno).

According to the studies of the projects included in the European program "Implementation of Sludge Management Infrastructure from Wastewater Treatment Plants" by Ministry of Environment and Energy, up to now (May 2024), a total of 19 projects have been included in the sector "Implementation of sludge management infrastructure from wastewater treatment plants," amounting to €140,761,787.00.

3 Sewage Sludge Treatment Methods

During the wastewater treatment process, sewage sludge is generated through primary, secondary, and sometimes tertiary treatment. These sludges are often combined into "raw" sewage sludge, containing approximately 1-4% solids. Treatment of sludge is necessary before disposal or further use. The primary objectives of sludge treatment are:

- Reducing the volume of sludge to lower treatment and transportation costs.
- Decreasing the presence of pathogens and minimizing foul odors [14].

4 Sludge Disposal

Historically, sewage sludge has been viewed as waste due to its potential high pollutant levels, including pathogens and other contaminants, resulting in its disposal [1]. With increasing population and urbanization, sludge production is rising, making traditional disposal methods unsustainable. Sustainable waste management prioritizes alternatives to landfilling, placing it as the least favorable option in the waste management hierarchy.

4.1 Sanitary Landfilling

The advantage of sanitary landfilling of sludge is that it prevents the release of pollutants and pathogens into the environment by concentrating the sludge in a single location [15]. As a disposal method, it is low-cost, and with the application of appropriate technology, methane (CH_4) recovery can be achieved. However, this only applies to cases where the landfill is properly constructed and maintained to reduce environmental risks [15]. Disadvantages include air emissions, water runoff – heavy metals, a burdened past due to previous use, the loss of useful components, space occupation, and the unutilized organic fraction [16].

4.2 Land Application

Treated sewage sludge can be repurposed for agricultural use due to its organic matter and nutrient richness, serving as a fertilizer or soil conditioner for various crops [1]. The application of sewage sludge provides nutrients and organic matter that offer positive agricultural benefits [17] and is of particular interest for the Mediterranean region due to the widespread lack of organic matter in the soil [18, 19]. However, there are contamination risks associated with soil application, such as heavy metals, organic pollutants, and pathogens. In addition to nutrients, sewage sludge also contains toxic heavy metals and organic pollutants [20, 21].

4.3 Green Energy

Energy recovery from sludge, primarily through anaerobic digestion, has become a prominent feature of sludge management strategies globally [22]. Biogas produced can be utilized for heat and electricity generation, with alternative methods including incineration, pyrolysis, and gasification [23]. Thermal methods of sludge disposal aim to reduce the pollutant load, achieve the maximum possible reduction of its volume, convert it into materials that are harmless to the environment and easily disposable, while simultaneously utilizing its calorific content. Generally, there is increasing interest in the use of thermal conversion in waste management technologies [24]. These methods generally aim to utilize waste streams while simultaneously reducing the risks associated with waste reuse [25]. Although the high cost of machinery is usually a significant obstacle to the implementation of thermal routes, investments in sludge treatment can become attractive if a 20% increase in energy prices in the international market is taken into account [26].

4.4 Use in the Construction Industry

Sewage sludge finds applications in construction, including its use in concrete mixes and the production of ceramics and glass [27]. The main metallic elements of sludge, including calcium, iron, and aluminum compounds, are included in cement mortars and other commercially used construction materials [28]. The construction industry is the most suitable sector of technological activity for the absorption of solid waste, due to the large quantity of raw materials and final products used [29].

4.5 Other Applications

The National Waste Management Plan (ESDA) outlines various alternative uses for sludge, such as mine deposit remediation, enhancing soil remediation, acting as an adsorbent material, aiding nursery development, and improving degraded soils [3].

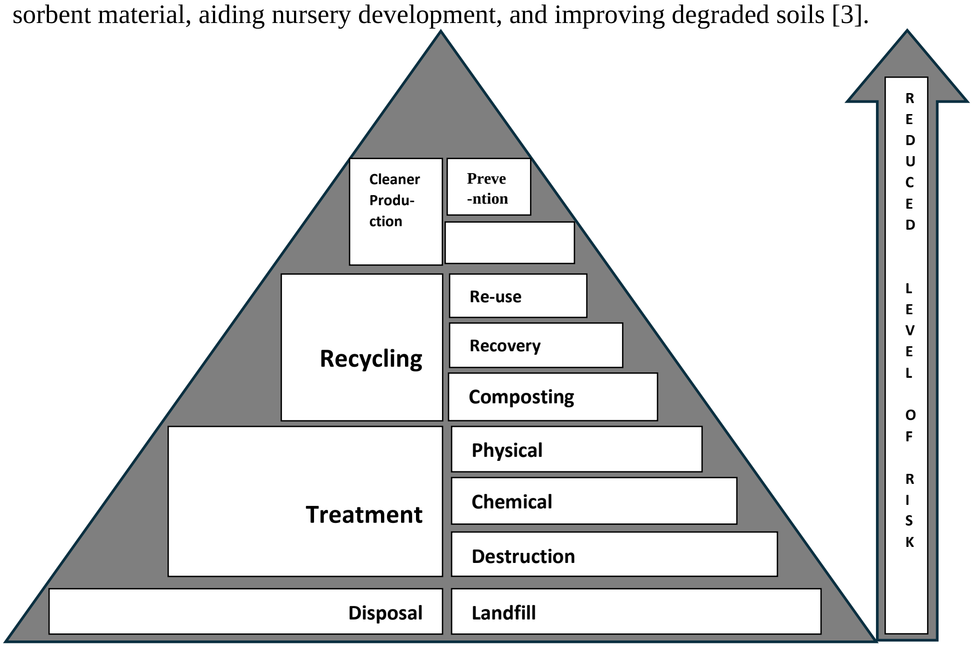


Fig. 1. Waste Management Hierarchy, Source WRC, 2009

In Spain, over one million tons are applied to the land annually (approximately 83% of the produced sludge) [19]. The application of sewage sludge provides nutrients and organic matter that offer positive agricultural benefits [17] and is of particular interest for the Mediterranean region due to the widespread lack of organic matter in the soil [18, 17]. Some authors have investigated the direct application of dried sewage sludge as an adsorbent [30]. Due to its high organic content, sludge has been proposed as a suitable and low-cost raw material for the production of activated carbon through pyrolysis [31, 32].

5 Production of sewage sludge

As it can be seen in the following Table 1, sludge production appears to vary significantly between the various EU countries. When searching for recent data on both the production and management of sludge from Wastewater Treatment Plants (WTPs) in the EU, it was found that there is a lack of continuous and reliable information as various member states do not submit regular data to the European Commission or do not submit data as required according to the European Directives. The "safest" data for sludge management essentially come from the first 15 member states (EU-15).

Table 1. Sludge production in the EU countries 2014-2020 (10^3tn in dry substance (ds)) (Eurostat, 2023) [34]

COUNTRIES	2014	2015	2016	2017	2018	2019	2020
AUSTRIA	239.04	n/a	237.94	n/a	234.48	233.56	228,81
BELGIUM	177.96(p)	172.20(p)	177.67(p)	170.80(p)	166.98(p)	164.00(p)	165.96(p)
BULGARIA	54.9	57.4	65.00	68.60	53.10	44.43	n/a
FRANCE	1,059.00	1238,00	1,006.00	1,174.00	n/a	n/a	n/a
GERMANY	1,830.82	1,820.57	1,794.36	1,785.55	1,761.62	1,749.86	n/a
DENMARK	n/a	n/a	n/a	n/a	n/a	n/a	n/a
GREECE	16.1	119.77	119.77	103.28	103.28	103.28	n/a
ESTONIA	19.91	19.11	18.65	20.94	25.54	19.48	18.99
UNITED KING-DOM	n/a	n/a	n/a	n/a	n/a	n/a	n/a
SPAIN	1,131.60	1,252.60	1,174.40	1,192.00	1,210.40	n/a	n/a
ITALY	n/a	n/a	n/a	n/a	n/a	n/a	n/a
NETHERLANDS	345.00	354.60	347.60	n/a	341.77	n/a	353.85
CROATIAN	16.31(p)	17.94	19.72	17.60	19.23	19.23	22.51
CYPRUS	6.16	6.70	7.41	7.17	8.41	n/a	n/a
LATVIA	22.00	21.92	25.92	24.94	24.59	24.18	23.15
LITHUANIA	40.71	44.45	44.42	42.49	44.19	39.94	41.05
LUXEMBOURG	n/a	9.16	8.92(p)	9.32(p)	9.08(p)	8.89(p)	9.47(p)
MALTA	8.50	8.44	10.77	10.30	8.28	9.69	10.36
HUNGARY	163.12	177.78	217.96	266.84	233.66	227.89	n/a
POLAND	556.00	568.00	568.33	584.45	583.07	574.64	568.86
PORTUGAL	85,89	n/a	119,17	n/a	n/a	n/a	n/a
ROMANIA	192.33	210.45	240.41	283.34	247.76	230.59	254.22
SLOVAKIA	56.88	56.24	53.05	54.52	55.93	54.83	55.52
SLOVENIA	28.30	29.10	32.80	36.70	38.10	34.80	31.00
SWEDEN	200.50	197.50	204.30	205.30	211.60	n/a	n/a
CZECH REPUBLIC	238.59	210.24	206.71	223.27	228.22	221.09	219.11
FINLAND	115.70	146.00	146.99	161.19	146.62	160.17	n/a
TOTAL	6,564.59	6,624.36	6,717.70	6,321.25	5,635.08	3,806.29	2,038.33

(p): Data provisional **n/a: not available**

Germany is the largest producer of sludge followed by the UK and France and together with Spain and Italy, it is estimated that these countries (the UK is no longer part of the EU) produced over 76% of the sludge produced in the EU-15 [33]. Eurostat figures for 2019 confirm this claim with Germany's annual sludge production rate amounting to 46% of the total sludge production in the 28-nation European Union.

As far as the EU-13 countries (countries that joined the EU after 2004) are concerned, Poland produces the largest amount of sludge with a percentage of 42% of the total amount of sludge produced by these member states, while at the opposite end is Malta with the smallest percentage of production. It should be noted that Poland, Hungary, and the Czech Republic account for more than 70% of the produced sludge in this group of member states (www.ec.europa.eu, last updated 11/28/2018) [34].

6 Sludge management data in European countries

The solid residue of wastewater treatment is sewage sludge whose nature is rich in nutrients, but also often filled with high concentrations of pollutants such as heavy metals, a fact that prompts countries to look for different ways to discard it.

Below are presented the methods of disposal of sludge from sewage treatment plants in European countries with data on treatment and disposal of sludge in the countries of the European Union.

In particular, the sludge treatment methods from E.E.L. in various European states are as follows [34-35-36]:

Austria uses aerobic and anaerobic digestion, mechanical dewatering, drying and composting, for sludge stabilization. Also, while initially disposal in agriculture was the most basic use of sludge, it has now been almost abandoned with 86% of the sludge being used for combustion and only 5% for agriculture.

Belgium applies aerobic or anaerobic stabilization, addition of improvers (lime or polymers), mechanical dehydration, thermal drying and in a few Sewage treatment plants (WWTPs) composting. Also in Belgium, the usual landfill method that was initially followed has been almost abandoned, with 80% of the sludge being disposed of in other methods such as incineration and 10% in burning and agriculture.

Aerobic digestion, mesophilic anaerobic digestion, calcification, dewatering with filter presses and long-term storage are used in Bulgaria. Composting is barely used at 7%, while 71% is allocated to agriculture.

In France, aerobic and anaerobic stabilization, calcification, composting, improvement by adding lime, dewatering with filter presses or centrifuges and drying are applied. Sludge from 1992 until today continues to be allocated mainly to agriculture at a rate of 65%.

In Germany, the most common sludge treatment method is thermal drying. Other methods also used are anaerobic stabilization, calcification, thermal stabilization and thermal anaerobic digestion (TPAD). The main method of sludge disposal was initially agriculture at a rate of 46% in 1992, while recently in 2021 combustion has taken its place at a rate of 55% with agriculture accepting only 30% of the produced sludge.

Mesophilic or thermophilic anaerobic digestion, aerobic digestion, liming, composting, thermal drying and pasteurization are practiced in Denmark. Only three values are available from Eurostat for the years 2007, 2008 and 2010, equal to 140.00 – 108.00 and 141.00 $*10^3$tn in dry substance (ds), respectively. Agriculture was initially the main method of disposal of sludge at a percentage of 65%, while recently, the disposal in agriculture and in combustion maintain almost equal percentages, 50% and 45% respectively.

In Greece, the stabilization methods applied are mesophilic anaerobic digestion, aerobic digestion, calcification, improvement with polymers, dehydration in drying beds, centrifuges or belt filter presses and solar drying. Composting is little applied (8% in 2014 and 0% in 2020). Regarding the sludge disposal methods, an analysis is carried out in the next thematic section.

The main method used in Estonia for sludge treatment is composting and mesophilic anaerobic digestion. Agriculture at 79% and composting at 15% are the main methods of sludge disposal.

In Ireland, thermophilic aerobic digestion, anaerobic stabilization, calcification, dewatering with centrifuges or belt filter presses, thermal drying and long-term storage are used. Ireland in 1992 had 43% of its sludge in landfill or 38% in surface water. Now, 70% of sludge is used in agriculture.

The most common treatment method in Spain is anaerobic stabilization. Other methods applied are aerobic digestion, calcification, thermal drying and long-term storage. Spain, from 1992 until today, disposes of sludge in agriculture at a rate of 83%.

Anaerobic digestion is mainly used in Italy, followed by aerobic digestion, calcification, composting, improvement with lime or ammonia, mechanical dehydration and where few Sewage treatment plants (WWTPs), thermal drying and pasteurization. From Eurostat, only one value is available for the year 2010, equal to 1,102.70 *103tn in dry substance (ds). For this reason, the country does not appear in the following Figure 2 with 2020 Eurostat data.

In the UK the most common technology is mesophilic anaerobic digestion and thermophilic aerobic digestion, calcification, composting, dewatering with filter presses or belt filter presses, thermal drying and long-term storage. From Eurostat, only one value is available for the year 2012, equal to 1,136.70 *103tn in dry substance (ds). The main mode of sludge disposal since 1992 remains agriculture at 78% for 2012. It should be emphasized that as of 2019 the United Kingdom is not a member of the European Union anymore (MS), and does not participate in Figure 2.

More generally, there is a wide variety of sludge treatment technologies used in the European Union of 27, which are related to the final disposal practices and the size of the waste treatment plants. Significant differences can be observed between EU member states, as well as between different regions of the same country (e.g. Belgium).

In particular, the Figure 2 lists the sludge disposal methods of European countries, for 2020.

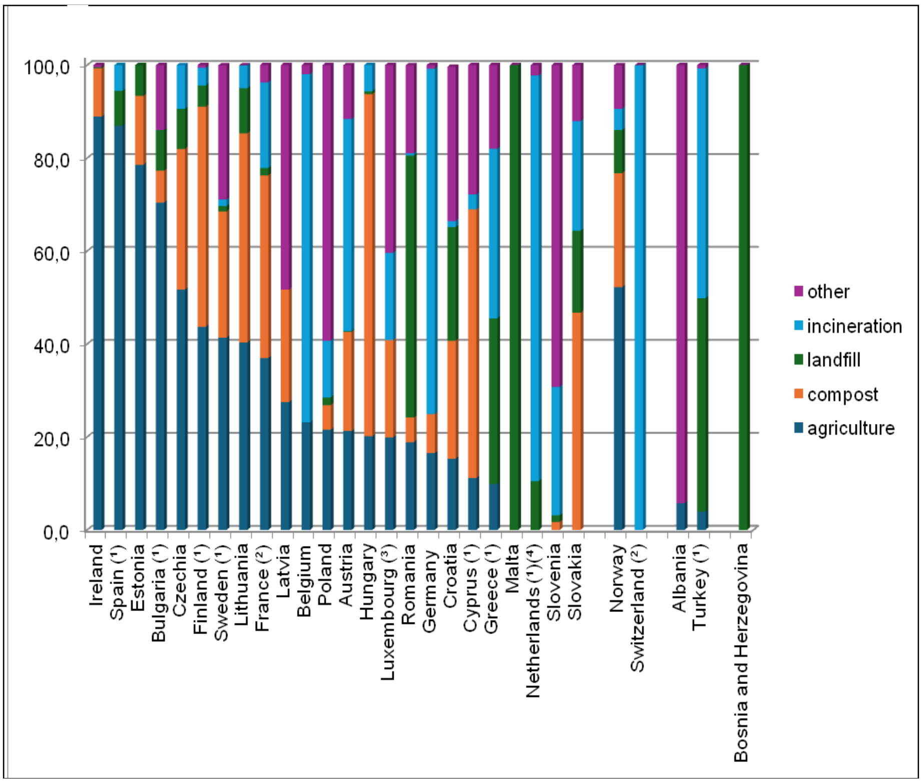


Fig. 2: Disposal of sewage sludge from municipal wastewater treatment by disposal method, 2020 (% of total) [39].

As there are more and more environmental concerns about reducing or eliminating the spread of pollutants to land, incineration is increasingly the method of choice: while the Netherlands (96%), Belgium (75%, provisional data), Germany (74%, 2019 data), Austria (52%), Greece (37%, 2019) and Luxembourg (34%, estimated) reported incineration as the main form of treatment for their disposal, disposal in controlled landfills was carried out as the main type of treatment only in Malta, Serbia, Bosnia and Herzegovina (in these countries it is the only form of treatment), Romania (55%), and Turkey (45 %).

7 Sludge management in Greece

Regarding the management of sludge from waste treatment plants in Greece, the reduction in the percentage of landfills, following the effort to harmonize the member states with the relevant Directive, is noticeable, from 98.5% in 1992 to 33% in 2014 [37-38]. The updated data for 2020 (2020 forecast with 2019 data) according to the data submitted to Eurostat which can be seen in Figure 3 above, 10% is allocated to agriculture, 35% to land restoration, 37.5% to incineration and the remaining 17.5% in other uses with the predominant disposal in landfill [39].

The quantitative targets of recovery (95% by weight) and disposal (5% by weight) of the produced sludge set by the 2015 National Waste Management Plan (ESDA) for 2020 were not achieved, according to the data also highlighted in the Early Warning Report of European Commission (SWD (2018) 418 final / 24.09.2018) more realistic targets were set for 2030 (five years earlier than the implementation schedule set by the European Union), in the National Waste Management Plan (ESDA) 2020 that mention 90% and .b. and disposal of up to 10% by weight of the produced sludge.

The recycling of sludge for agricultural purposes is an alternative solution to handle the continuous increase in the quantities produced in recent years [40]. The utilization of sludge in today's agriculture represents a widespread practice in developed countries, as an alternative that is more efficient than incineration or storage [41]. But in addition to nutrients, sewage sludge also contains toxic heavy metals and organic pollutants [39]. On 04-21-2023, Official Gazette 2692/B/2023 was published, which aims to harmonize the National legislation with the provisions of the Directives of the European Parliament regarding the territorial utilization of this sludge in agriculture and soil restoration. With the above decision, the use of treated sludge is prohibited in: **a**. Grounds frozen or covered with snow, **b.** Soils flooded or saturated with water, **c.** Soils with a pH lower than 5, **d.** Parks and groves with recreation areas and playgrounds and in outdoor forest recreation areas, **e.** Sports fields, **f.** Natural forests and in forested and reforested areas, **g.** Soils that are less than 50 meters from lakes, rivers and streams, **i.** Wetlands and marshy areas **j.** Very light soils (sandy - sandy loam). In addition, the requirement for a license to use sludge for disposal in agriculture and soil restoration is established from 04-21-2023.

In Greece, since 2008, Municipal Water Supply & Sewerage Company (MWSSC) of Larisa implements a plan for the disposal of sludge in agriculture, in collaboration with the agricultural producers of the Thessalian plain [42]. Additionally, the most important project is the disposal of sludge for agricultural crops on behalf of Municipal Water Supply & Sewerage Company (MWSSC) of Thessalloniki approximately 45,000 tons of calcified sludge from the facilities of MWSSC of Thessaloniki in Sindo which were transported and distributed to plots of land in the Prefecture of Thessaloniki from the Spring of 2012 to the Spring of 2015 in a total of seven growing seasons. In April 2016, MWSSC of Katerini implemented, on a pilot basis, the application of 390.6 tn of sludge from the Municipal Water and Wastewater Treatment Plant (MWWTP) of Korinos and Katerini to crops in the area. In 2016, the MWSSC of Ioannina built an open composting unit for the management of biological cleaning sludge. In addition, it should be considered that in the existing Mud Treatment Facility, which operates on the grounds of the Ioannina Municipal Water and Wastewater Treatment Plant, the sewage sludge of the Ioannina MWWTP is already processed. With the December 2013 decision to approve environmental conditions, the permission has been given for the treatment of sewage sludge originating from the MWWTP of Igoumenitsa.

Following the Publication of Official Gazette 2692/B/21-04-2023 and the establishment of strict restrictions and continuous controls for the proper use of treated sludge in agriculture, the inclusion of other parameters such as conventional fertilization, and above all, the control of the quality of sludge and the care to avoid possible failure and non-observance of the sludge application study in each territorial area, most producers of treated sludge, where are the MWSSC, have turned to other methods of its disposal.

Based on the data from the Union of Municipal Water Supply and Sewerage Companies, the tendency is to increase, as much as possible, the share of thermal methods and drying. At the Urban Wastewater Treatment Unit (UWTU) of Psittaleia, the sludge produced is dewatered, dried, turned into powder and used as an alternative fuel in the cement industry. At MWWTP of Thessaloniki, a thermal sludge drying unit with two (2) parallel drying lines is used for sludge management. A small solar drying greenhouse has been installed on a pilot basis at MWWTP of Kavala premises since 2010, in which quantities of dewatered sludge are transported and subjected to natural drying. Samples of these sludges have been tested experimentally and found to yield a sufficient calorific value equal to 17 MJ/kg liquid to achieve self-sustaining combustion of the sludge [6]. Fo.S.D.A. (Solid Waste Management Authority) of the Northern Plains in Heraklion, Crete, also applies contact-based aging drying under a greenhouse.

In particular, in Greece after 01/17/2023 and the inclusion of the project "Treatment and purification of urban wastewater in environmentally sensitive settlements and modernization of facilities" of the Recovery and Resilience Fund (OPS Code TA 5164462), many projects have been financed and are in the implementation stage, concerning **a.** Sewer network infrastructure and sewage treatment facilities, **b.** Upgrading, expanding and modernizing sewage treatment facilities and reuse of treated water and **c.** Implementation of sludge management infrastructure from sewage plants [3].

According to the studies of the projects that are included in the European program "Implementation of sludge management infrastructure from sewage treatment plants" of the Ministry of the Interior, there is no composting plant construction project among the 19 included projects, except those for the use of sludge in co-composting after the sludge has drying. By the submitted studies, 122,113 tons of sludge can be treated annually with the aim of reducing the volume of landfill disposal to 5%. Amount exceeding the annual sludge produced nationally. In 2019 the amount of produced sludge was 103,280 tons approximately.

A total of 19 projects, shown in Table 2, for a total amt. of 140,761,787.00 € have been included in the above European program in the field of Implementation of sludge management infrastructure from sewage plants. The obligation date for the completion of the above projects as well as all the others that will be included until 12/31/2023 in the above European program is 12/31/2025 [42].

Table 2. SUB-PROJECTS C- Implementation of sludge management infrastructure from sewage treatment plants

A/A	BUDGET (€)	CAPACITY (tn/y)	BENEFICIARY	INTEGRATED PROJECT
1	8,800,000	8,000	MWSSC Ioannina	Construction of a solar drying unit Ilyos EEL Ioannina
2	7,658,731	8,001	MWSSC Larisa	Solar sludge drying unit EEL Larisa with operation and maintenance
3	8,350,147	2,053	MWSSC Chania	EEL Chania sludge management infrastructure and photovoltaic plant installation
4	2,285,000	3,350	MWSSC Arta	EEL Arta Dewatered Sludge Treatment Unit
5	5,655,000	7,395	MWSSC Xanthi	Implementation of a sludge drying unit EEL Xanthi
6	4,792,587	2,711	Solid Waste Management Agency of Northern Plains SA OSA	Center for the treatment of sludge from wastewater treatment facilities of OSA-members FOSDA of the Northern Plains
7	5,950,000	6,240	MWSSC Lamia	Solar sludge drying unit EEL Lamia
8	6,400,000	8,400	MWSSC Drama	Construction of a Solar Sludge Drying Unit EEL Drama
9	3,782,650[c]	2,683	MWSSC Livadia	Implementation of a sludge management unit from the Livadia and Kyriaki wastewater treatment facilities
10	19,717,611	15,125	Union for Waste Management of Crete	Sludge treatment center of Heraklion PE sewage treatment facilities Crete
11	2,441,674	1,800	MWSSC Agios Nikolaos	Dewatered sludge treatment unit from the EEL of the Municipality of Agios Nikolaos Ctete
12	6,900,000	11,000	MWSSC Aegialia	Supply, installation, and operation of equipment for thermal drying of EEL Aigio sludge
13	3,750,000	2,000	MWSSC Orestiada	Construction of a solar sludge drying unit of EEL Orestiada
14	6,428,500	11,012	MWSSC Kalamata	EEL Kalamata Sludge Solar Drying Unit
15	9,936,000	1,987	MWSSC Serres	Construction of a solar drying unit for the sludge of the EEL Municipality of Serres
16	7,797,571	4,000	MWSSC Alexandroupolis	Solar drying of sludge EEL Alexandroupolis.
17	7,916,316	3,650	MWSSC Kilkis	Sewage sludge treatment PE Kilkis
18	12,200,000	9,125	MWSSC Volos	Integrated management and utilization of sludge from EEL Volos
19	10,000,000	13,581	MWSSC Kavalas	Construction of an advanced sludge treatment unit by the EEL of the Municipalities of Kavala and Pangaio

(MWSSC): Municipal Water Supply & Sewerage Company **(C): contracted**

Therefore, according to the above data, the growing trend towards thermal treatment of sludge with drying methods (solar, etc.) is confirmed, and by 2025 will have changed the data on the disposal of treated sludge in Greece.

Following the Early Warning Report of the European Commission (SWD (2018) 418 final / 24.09.2018), it was realized that the quantitative goals of recovery (95% by weight) and disposal (5% by weight) of the produced sludge in WWTP that had been set by the ECHR 2015 for 2020 were unattainable. The new ESDA2020 set more realistic goals which, after the implementation of the European program "Treatment and purification of urban wastewater of environmentally sensitive settlements and modernization of facilities" on 31-12-2025, can be implemented by 2030.

The largest percentage of the total sludge produced in Greece comes from Attica (50.2%), followed by Central Macedonia (14.7%), the South Aegean with 5.1%, Thessaly (5%), Western Greece (4.0%), Epirus (3.9%), Eastern Macedonia and Thrace and Crete with 3.8% respectively, Central Greece (3.7%), Peloponnese (2.5%), the Ionian Islands (1.4%), the North Aegean with 1 ,0%, and Western Macedonia (0.9%) [21]. Attica and Thessaloniki are already successfully managing the produced sludge with the Psittaleia and Sindos plants, according to the data published with the ESDA 2020.

According to the submitted data of the country's Wastewater Treatment Facilities, in the Registry, Licensing and Statistical Waste Department of the Waste Management Directorate of the Ministry of the Interior, for the reference year 2019 until January 2021, the recovery rates in the Regions of the country are for Attica 98.2% followed by Western Macedonia 90.3%, Central Macedonia 67.3%, Peloponnese 51.9%, Central Greece 46.9%, Eastern Macedonia and Thrace 38.2 %, Epirus 31.8%, Thessaly 26.9%, Western Greece 10.2%, Crete 4.6%, North Aegean, South Aegean and Ionian Islands 0.0%. That is, only the Region of Attica (98.2%) and the Region of Western Macedonia (90.3%) achieve the recovery targets set with the ESDA 2020. Consequently, 51.1% of the produced sludge in Greece can so far be recovered according to the National plan.

Observing the beneficiaries of Table 2 and the regions to which they belong, we conclude that 6 of the 19 projects are implemented in the Region of Eastern Macedonia and Thrace, 4 of the 19 projects are implemented in the Region of Crete, 2 of the 19 projects respectively are implemented in the Regions of Epirus, Central Greece and Thessaly, while 1 of the 19 projects are respectively implemented in the Regions of Western Greece, Peloponnese and Central Macedonia. While the Regions of Attica, North Aegean, Ionian Islands, Western Macedonia, and South Aegean are not beneficiaries. Consequently, since the Region of Attica and the Region of Western Macedonia already comply with the National plan for sludge recovery, only 7.5% of the produced sludge will not be recovered.

The National plan for the recovery of sludge until 2030 stipulates that up to 10% of the produced sludge may be available for landfill. Consequently, we conclude the necessity of implementing the projects in Table 2, which will achieve the national goals for sludge management.

8 Discussion

Sludge, when processed into various materials such as granules, fertilizers, or compost, proves to be highly beneficial for agricultural purposes and natural applications, provided heavy metals and other contaminants are adequately removed. Compost derived from sludge treatment can serve purposes like soil conservation or the restoration of degraded areas through re-cultivation. Following the Publication of Official Gazette 2692/B/21-04-2023 entitled: "Measures, conditions and procedures for the use of treated sludge in agriculture and soil restoration", within which strict restrictions and continuous controls are set for the correct use of treated sludge in agriculture, most treated sludge producers, as MWSSC for example, have turned to other methods of treated sludge disposal.

In today's era, Goswami & Thakur [43] state that globally, challenges arise primarily due to the increasing population and the ensuing issues related to water, energy, and food security. Additionally, greenhouse gas emissions and climate change pose global threats that widen the gap between economic development and environmental sustainability. Therefore, the need for implementing sustainable practices and circular economy technologies to prevent climate change and meet the growing energy demands is imperative, especially in developing countries.

Reducing the production of sewage sludge from wastewater treatment is a primary factor for its successful management. According to Collivignarelli et al. [44], the quantity of sewage sludge must be minimized to comply with the European Directive 2018/851, and due to its high management cost, which represents approximately 50% of the total operational cost of a WWTP. The concept of the circular economy serves as an economic model aimed at enhancing environmental sustainability, fostering economic growth, and promoting social equity. By prioritizing the efficient use and reuse of resources, it seeks to benefit not only the present generation but also future ones [45, 46, 47]. At the microeconomic level, implementing the circular economy leads to enhancements in production models and fosters greater collaboration with other firms within the supply chain. This collaboration aims to achieve a more economically efficient closed-loop cycle, wherein resources are utilized and reused optimally [48, 49]. According to circular economy principles, the reuse, treatment, and renovation of products lead to a reduced demand for resources and energy. This approach promotes sustainability by maximizing the lifespan and value of materials and products [46, 48]. A key assumption of the circular economy is that incineration for energy recovery is a preferable option, while waste landfilling is considered the last resort. This approach ensures that the production value chain and product life cycle maintain optimal effectiveness and quality whenever possible, and maximize energy efficiency [50, 45, 46].

If sludge fails to meet legislative requirements, the most cost-effective method of utilization is through thermal methods such as incineration or co-incineration. Current plans for Greece propose primarily incineration, with an alternative option being the use of sludge as a fuel in cement industries.

Energy production processes from renewable sources such as, for example, solar energy, tidal energy, biomass, or biofuels, cause many adverse economic and social effects, because it also causes a reduction in the areas covered by forests and permanent pastures [51].

In Greece after the inclusion of the project "Treatment and purification of urban wastewater in environmentally sensitive settlements and modernization of facilities" of the Recovery and Resilience Fund from 01/17/2023, there is a growing trend towards thermal treatment of sludge with drying methods (solar etc.) which by 2025 will have changed the facts of the disposal of treated sludge in Greece. Due to the satisfactory calorific value of sewage sludge, there has been significant interest in its potential use as a renewable fuel. Analysis of sewage sludge from the Eastern Macedonia and Thrace region has revealed its suitability as an energy and heat source in both conventional and emerging technologies. Additionally, it can serve as a substrate for fertilization and soil remediation, provided that the technology utilized yields a high-quality product [6].

Aligned with the principles of a closed circular economy, sustainable sewage sludge management should prioritize recovery over disposal. Implementing solutions already established in the European region, which promote circular economy principles and sustainable development, can lead to environmental benefits such as reduced greenhouse gas emissions, enhanced soil conditions, and decreased reliance on fossil fuels. The economic potential of these initiatives lies in several factors:

- Decreasing compensation costs associated with traditional waste treatment methods, particularly landfill disposal.
- Lowering the expenses related to waste treatment, sanitation, and remediation.
- Reducing energy costs by utilizing biogas and biofuels as alternatives to traditional fuels, thus partially replacing them.

The recovery of value-added products, such as biogas, biofuels, building materials, soot, and nutrients (nitrogen and phosphorus) from sewage sludge, represents an option for sustainable management. This approach reduces dependence on non-renewable resources, contributing to the conservation of natural resources and the reduction of environmental pollution and human health risks. However, despite the advancement of resource recovery technologies, most technologies are still in their early stages (Gurjar & Tyagi, 2017) [52]. Currently, biofuel is a fundamental renewable energy source. Utilizing biofuels offers the potential to reduce greenhouse gas emissions compared to crude oil fuels and aids in storing CO_2 in the soil. This benefit arises from the methods employed in producing biofuels and their byproducts. Maintaining soil organic carbon during the initial stages of biofuel development mitigates climate change [53, 54].

Biological sludge is a renewable natural resource, and its rational utilization is vital for the development of the circular economy and the sustainable management of natural resources, one of the main priorities of modern society.

In this direction, the plan for sustainable sludge management in Greece must:

i. Meet the country's needs for compliance with Directive 91/271/EEC, which includes studies, construction of new infrastructure for urban wastewater and sludge treatment, improvement of the operation and upgrade of existing wastewater treatment plants (WWTPs), sludge utilization projects, and effluent reuse projects, as presented in the updated (May 2022) "National Operational Plan for Wastewater."

ii. Adopt national criteria for the design of urban wastewater treatment infrastructure, as mentioned above, aiming to reduce the produced sludge and implement the circular economy.
iii. Establish the use of sewage sludge as a renewable resource for the recovery of value-added products.

However, the current reality in Greece is not so ideal. With the decision of 15.10.2015, the Court of Justice of the European Union (CJEU) imposed a financial penalty on Greece for failing to comply with an earlier judgment concerning the treatment of urban wastewater. Specifically, the Hellenic Republic was required to pay the European Commission "a penalty payment of €3,640,000 per six months of delay in taking the measures necessary to comply with the judgment Commission v. Greece (C-440/06, EU:C:2007:642), from the date of publication of the present judgment until the full implementation of the judgment Commission v. Greece (C-440/06, EU:C:2007:642)." (Court of Justice of the European Union. Judgment of the Court (Fourth Chamber) of 15 October 2015, European Commission v. Hellenic Republic, C-167/14.)

In November 2015, Greece was referred again for non-compliance (for 11 years) with an earlier judgment from June 24, 2004, concerning the lack of a sewer system in the Thriassio Plain and the discharge of untreated urban wastewater into the sensitive area of Elefsina Bay (European Commission - Press release. (14.11.2015). Commission proposed fines and referred GREECE back to the Court of Justice of the EU over persistent poor wastewater treatment. [55]

According to the eighth implementation report (2016) of the Urban Wastewater Directive, in 2012, there were 33 settlements in Greece where urban wastewater management was not compliant with the legislation (reporting date 31.12.2012). (European Commission. (2016). Urban wastewater. Implementation Reports. 8th Technical assessment of information on the Implementation of Council Directive 91/271/EEC. Annex V. Table 9-4-1. Retrieved on 16.7.2016 [56].

Certainly, Greece is not the only country that has violated the related directive or has been fined for non-compliance with a court ruling on the same issue. However, considering the overall economic and environmental challenges the country faces, these decisions are a particularly unpleasant development.

Greece also faces many similar issues in national courts. In another significant decision regarding the Asopos ecosystem (Council of State (5th Chamber) 3943/2015 and Council of State (5th Chamber) 4368/2015), the administration was obliged to take appropriate preventive and remedial measures as defined by the provisions of the Environmental Liability Directive.

Furthermore, according to the relevant database of the Special Secretariat for Water, a significant number of wastewater treatment plants either did not report data or did not achieve the required limit values (data from 2015). (Special Secretariat for Water. (2016). Wastewater Treatment Plants. Monitoring Operation Database [57]).

Therefore, the available data indicate that the country continues to face significant challenges and major problems in implementing the legislative framework concerning broader environmental issues and specifically the management of wastewater and sludge, both internationally and nationally.

Consequently, it is imperative to implement the aforementioned measures, which will contribute to reducing the environmental impacts of sludge disposal, resolve the growing problem of managing this waste, and support the new economic model of sustainable development of the circular economy.

9 Conclusions

In recent years, significant advancements in water and wastewater management have resulted in substantial improvements in sludge management in Greece. These improvements indicate promising prospects for further enhancement, as evidenced by proposed national planning initiatives. The deliberation of the complex issue of managing sludge, produced by municipal sewage treatment plants, and chooses of the appropriate strategy for municipal sewage sludge management, is a complex problem. The resolution of this issue should comprehensively consider environmental and economic factors, alongside numerous zoning constraints related to both new and existing facilities. It should involve a thorough analysis of the market for the final product, assessing the size of the target market, and determining the implementation timeline for each proposed solution. This holistic approach will ensure that the chosen strategy not only addresses sludge management effectively but also aligns with broader environmental goals and economic considerations.

Taking into account the social acceptance factor, which was not reflected in the research of the current national planning for Greece, and which should focus on the diversity of the various regional departments of the Greek space, with the aim of sludge recovery, for the benefit of agriculture or energy utilization as a priority, in accordance with the ESDA, this may be a future research topic.

References

1. TCG : Homepage, https://www.westerncape.gov.za/eadp/sites/eadp.westerncape.gov.za/files/atoms/files/Sewage%20Sludge%20Status%20Quo_12032021.pdf, 2024/20/3.
2. Shaddel, S., Bakhtiary-Davijany, H., Kabbe, C., Dadgar, F., and Osterhus. Sustainable Sewage Sludge Management: From Current Practices to Emerging Nutrient Recovery Technologies. Sustainability. 11(3435):1-2, (2019).
3. National Waste Management Plan, Official Government Gazette 185/B of September 29, 2020, (2020).
4. Ministerial decision Ministry of energy & environment/DDA/41828/630/21-04-2023, Official Gazette 2692/B/2023/21-04-2023, (2023).
5. K. Kołodziejczyk, Designing multiflux settling tank by using a numerical simulation of flow, Wydawnictwo SIGMA-NOT: Przemysł Chemiczny, T. 96- nr 8, 1687–1690 (2017)
6. K. Eleftheriadou, A. Evangelou and D. Komilis, Characterizing wastewater sludge in the Region of East Macedonia and Thrace, IWA Regional Symposium on Water, Wastewater and Environment: Traditions and Culture. Patras, 991-1001, TCG (2014).

7. Christodoulou A. & Stamatelatou K. Overview of legislation on sewage sludge management in developed countries worldwide. Water Science and Technology, 73:453–462, (2016).
8. Jin et al., Influence of pyrolysis temperature on properties and environmental safety of heavy metals in biochars derived from municipal sewage sludge, Journal of Hazardous Materials, Elsevier, Volume 320, 15 December 2016, Pages 417-426.
9. Prajapat N., Raval A.D., Pitroda J.R., Kulkarni V.V., A Review on Sewage Sludge Applications and Utilization. Int. J. Eng. Res. 2019, 8, 109–112.
10. Speight J.G. & Singh K., Environmental Management of Energy from Biofuels and Biofeedstocks, John Wiley & Sons, Inc.: Hoboken, NJ, USA, 2014.
11. Aziz S.Q. & Mustafa, J.S., Wastewater sludge characteristics, treatment techniques, and energy production. Recycl. Sustain. Develop. 2022, 15, 9–27.
12. TCG : Homepage, https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Water_statistics, 2024/20/3.
13. Approval of the National Waste Management Plan (ESDA) Ministerial decision Ministry of energy & environment 51373/4684/2015 (Government Gazette 2706/B` 15.12.2015) Sanction of the National Management Plan.
14. Dr T. D. Evans, Sewage sludge: Operational and Environmental Issues. Foundation for Water Research, United Kingdom, Fourth Edition (2016).
15. TCG: Homepage, https://extension.psu.edu/what-is-sewage-sludge-and-what-can-be-done-with-it , 2023/11/4.
16. Kartsonas N., Angelakis A., Diavatis I., Evmorphopoulou A., Mamais D., Bosdogianni A., Stamou A., Vourvachi N., Alternative methods of managing by-products from wastewater treatment facilities. Proceedings of the 5th International Conference on Environmental Technology (ed Technical Chamber of Greece) - HELECO 2005, February 3-6, Athens, Greece.
17. R.P. Singh and M. Agrawal, Potential benefits and risks of land application of sewage sludge, Waste Management, Elsevier, 2008, Volume 28, Issue 2, Pages 347-358.
18. J.C García-Gil, C Plaza, P Soler-Rovira, A Polo, Long-term effects of municipal solid waste compost application on soil enzyme activities and microbial biomass, Soil Biology and Biochemistry, Elsevier, November 2000, Volume 32, Issue 13, Pages 1907-1913.
19. Eva Lloret et all., Sewage sludge addition modifies soil microbial communities and plant performance depending on the sludge stabilization process, Applied Soil Ecology, Elsevier, May 2016, Volume 101, Pages 37-46.
20. Maria Oliva, Felipe Vargas, Mauricio Lopez, Designing the incineration process for improving the cementitious performance of sewage sludge ash in Portland and blended cement systems, Journal of Cleaner Production, Elsevier, 20 June 2019, Volume 223, Pages 1029-1041.
21. WIECHMANN B., DIENEMANN C., KABBE C., BRANDT S., VOGEL I., ROSKOSCH A. Sewage sludge management in Germany, Dessau-Rosslau, German Environmental Agency, 2013.
22. Liew, AG, Idris, A., Wong, CHK, Samaad, AA, Noor, MJMM and Baki, Incorporation of sludge in clay brick and its characterization. Waste Management & Research, 2004, 22 (4): 226-233.
23. Kowalski, Z.; Makara, A.; Kulczycka, J.; Generowicz, A.; Kwa´snicki, P.; Ciuła, J.; Gronba-Chyła, Conversion of Sewage Sludge into Biofuels via Different Pathways and

Their Use in Agriculture: A Comprehensive Review A. Conversion of Sewage Sludge into Biofuels via Different Pathways and Their Use in Agriculture: A Comprehensive Review. Energies (MDPI), 2024,17, 1383.

24. Syed Shatir A. Syed-Hassan at all., Thermochemical processing of sewage sludge to energy and fuel: Fundamentals, challenges and considerations, Renewable and Sustainable Energy Reviews, Elsevier, December 2017, Volume 80, Pages 888-913.
25. Atul Kumar and S.R. Samadder, A review on technological options of waste to energy for effective management of municipal solid waste, Waste Management, Elsevier, November 2017, Volume 69, Pages 407-422.
26. G. Houillon and O. Jolliet, Life cycle assessment of processes for the treatment of wastewater urban sludge: energy and global warming analysis, Journal of Cleaner Production, Elsevier, February 2005, Volume 13, Issue 3, Pages 287-299.
27. Johnson, OA, Napiah, M. and Kamaruddin, I., Potential uses of waste sludge in the construction industry. Research Journal of Applied Sciences, Engineering and Technology, 2014, 8(4): 565-570.
28. Lesław Świerczek at all., The potential of raw sewage sludge in construction industry – A review, Journal of Cleaner Production, Elsevier, 1 November 2018, Volume 200, Pages 342-356.
29. J. E. Alleman, E. H. Bryan, T. A. Stumm, W. W. Marlow, R. C. Hocevar, Sludge-Amended Brick Production: Applicability for Metal-Laden Residues, Water Science Technology , 1990, 22 (12): 309–317.
30. Andrey Bagreev and Teresa J. Bandosz, H2S Adsorption/Oxidation on Materials Obtained Using Sulfuric Acid Activation of Sewage Sludge-Derived Fertilizer, Journal of Colloid and Interface Science, Elsevier, 1 August 2002, Volume 252, Issue 1, Pages 188-194.
31. Pejman Hadi et all, A critical review on preparation, characterization and utilization of sludge-derived activated carbons for wastewater treatment, Chemical Engineering Journal, Elsevier, 15 January 2015, Volume 260, Pages 895-906.
32. Anna Zielińska & Patryk Oleszczuk, Evaluation of sewage sludge and slow pyrolyzed sewage sludge-derived biochar for adsorption of phenanthrene and pyrene, Bioresource Technology, Elsevier, September 2015, Volume 192, Pages 618-626.
33. A Raheem, VS Sikarwar, J He, W Dastyar, Dionysios D. Dionysiou, Wei Wang, Ming Zhao, Opportunities and challenges in sustainable treatment and resource reuse of sewage sludge: A review, - Chemical Engineering Journal, 2018, 337:616-641.
34. TCG Homepage, https://ec.europa.eu/eurostat/databrowser/product/page/ten00030 , 2023/11/14.
35. D. Vouk, D. Nakic, N. Stirmer and CR Cheeseman, Use of sewage sludge ash in cementitious materials, Reviews on Advanced Materials Science, 2017, 49, 158-17 .
36. TCG Homepage, https://commission.europa.eu/system/files/2020-10/env_sp_2020_2024_en.pdf, 2024/05/21.
37. Kelessidis, A. and Stasinakis, 'Comparative study of the methods used for treatment and final disposal of sewage sludge in European countries', Waste Management, 2012, Vol. 32, No. 6, pp.1186–1195.
38. TCG Homepage, https://www.eydap.gr/Investors/Presentations/?id=4 ,2023/11/14.
39. TCG Homepage, https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Water_statistics, 2024/05/21.

40. A Passuello, M Mari, M Nadal, M Schuhmacher, José L. Domingo, POP accumulation in the food chain: integrated risk model for sewage sludge application in agricultural soils, Environment International, Elsevier, 2010.
41. Paul K. Boss and Curtis M. Kalua, Evolution of Volatile Compounds during the Development of Cabernet Sauvignon Grapes, Journal of Agricultural and Food Chemistry, 2009.
42. TCG Homepage, https://edeya.gr/index.php/el/draseis/taktikes-gs/eisigiseis-27is-gs-tis-edeya-xalkida-1/337-diachirisiiliosegatastaseonepexergasiaslimatonifistameni-katastasiikonomikidiastasi/file, 2024/05/21.
43. Goswami R., Thakur R., Valorizing sludge: a biorefinery perspective prospecting for sustainable development (Ch. 21 of book: Clean Energy and Resource Recovery) Elsevier, 2022.
44. Collivignarelli M.C., Abbà A., Carnevale Miino M., Torretta V., What Advanced Treatments Can Be Used to Minimize the Production of Sewage Sludge in WWTPs, 2019, Applied Sciences, 9, 2650.
45. Ellen MacArthur Foundation. Towards the Circular Economy, 2014, Vol. 3: Accelerating the Scale-up across Global Supply Chains.
46. Ghisellini P., Cialani C., Ulgiati S., A review on circular economy: The expected transition to a balanced interplay of environmental and economic systems. J. Clean. Prod. 2016, 114, 11–32.
47. Korhonen J., Honkasalo A., Seppälä J., Circular economy: The concept and its limitations. Ecol. Econ. 2018, 143, 37–46.
48. Kowalski Z. and Makara A., The circular economy model used in the Polish agro-food consortium: A case study. J. Clean. Prod. 2021, 284, 124751
49. Gherghel A., Teodosiu C., De Gisi S., A review on wastewater sludge valorisation and its challenges in the context of a circular economy. J. Clean. Prod. 2019, 228, 244–263
50. Bonfiglioli L., Bianchini A., Pellegrini M., Saccani C. Sewage sludge: Characteristics and recovery options. J. Alma Mater Stud. Univ. Di Bologna 2014, 1–21
51. Różycki S., Kowalski W. P., Cavitation generators in biomass liquefaction Technologies, Przemysł Chemiczny, 2017, 96, 1716–1618.
52. Gurjar B. R., Tyagi V. K., Sludge Management, CRC Press - Taylor & Francis Group, 2017.
53. Osman A.I., Mehta N., Elgarahy A.M., Al-Hinai A., Al-Muhtaseb A.H., Rooney D.W., Conversion of biomass to biofuels and life cycle assessment: A review. Environ. Chem. Lett. 2021, 19, 4075–4118.
54. Huang C., Mohamed B.A., Li L.Y., Comparative life-cycle energy and environmental analysis of sewage sludge and biomass co-pyrolysis for biofuel and biochar production. Chem. Eng. J. 2023, 457, 141284.
55. TCG Homepage, http://europa.eu/rapid/press-release_IP-15-6009_en.htm, 2024/05/21
56. TCG Homepage, http://ec.europa.eu/environment/water/waterurbanwaste/implementation/implementationports_en.htm, 2024/05/21
57. TCG Homepage, http://astikalimata.ypeka.gr/Services/Pages/Browse.aspx, 2024/05/21