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Sustainable sewage sludge management in Morocco: Constraints and solutions

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Abstract

The remarkable development of sanitation in Morocco has inevitably led to the production of sludge generated from wastewater treatment plants in increasing quantities. Consequently, the problem of sludge management becomes persistent and worrying.

The aim of this paper was to contribute to the study of sewage sludge management issue in Morocco by identifying the various constraints hampering the sustainable disposal and/or recovery of municipal sewage sludge and drawing up recommendations for the decision-makers. Moreover, in the context of improving by learning from best practices and seeking common solutions regarding this problematic, benchmarking with other countries has been conducted as well.

To carry out this study, a methodological approach was defined based on bibliographic research, surveys, interviews and benchmarking.

The constraints hampering the sustainable management of sludge are numerous and complex, they have not been technical and environmental but also a regulatory, institutional-organizational and economic-financial nature yet. Therefore, municipalities, government and academia ideally would be encouraged to participate in the decision-making process regarding the management of sewage sludge. Technical solutions, when coupled with stakeholder participation, can lead to policy implementation with a higher chance of improving the present situation.

In the case of Morocco, when comparing with others sludge recovery and disposal routes, land application (reuse in agriculture, silviculture and rehabilitation of degraded soils) remains the most environmentally friendly option, as well as a sustainable and economically viable solution.

Key words: *disposal, recovery, sewage sludge, sustainable management, wastewater, wastewater treatment plant*

INTRODUCTION

The quantity of worldwide wastewater has been increasing rapidly in the last decades due to significant population growth and increased use of fresh water for various purposes. Wastewater, if not properly treated, can harm the environment and public health.

In Morocco, to surmount the delay in the sanitation sector, in 2005, the government adopted the National Sanitation Program with the objective of improving the health conditions of 10 million inhabitants in 330 Moroccan cities and towns by the year 2020. This ambitious program has since led to the construction of more than 130 wastewater treatment plants and a national wastewater treatment rate of 45% in 2017 instead of 7% in 2007 [DGCL 2017].

This important development of sanitation in Morocco has caused a significant increase in the flow of generated sewage sludge. Therefore, and since the national sanitation program did not integrate the sludge component, the sewage sludge management issue has arisen and become persistent and worrying and encourages the implementation of a sustainable strategy so as not to compromise the future of sanitation in Morocco.

After explaining the extent of sludge management problematic in Morocco, the aim of this paper was the contribution to the study of sewage sludge management issue in Morocco by identifying the various constraints hampering the sustainable disposal and/or recovery of municipal sewage sludge and drawing up recommendations for the decision-makers. Moreover, in the context of improving by learning from best practices and seeking common solutions regarding this problematic, benchmarking with other countries has been conducted as well.

STUDY METHOD

Morocco, like many countries in the world, has not made progress in setting up sludge recovery and disposal strategy yet, due to several constraints hampering its development. The constraints are numerous and complex and have different dimensions: regulatory, institutional-organizational, economic-financial, technical and environmental dimensions.

To contribute to the study of sewage sludge management issue in Morocco this study was carried out using a methodological approach based on bibliographic research, interviews and surveys. This methodology has allowed the explanation of the extent of sludge management problematic in Morocco and the identification of the various constraints hampering the sustainable disposal of sewage sludge,

Moreover, in the context of improving by learning from best practices and seeking common solutions regarding this problematic, benchmarking has been conducted as wellwith other countries from Europe (Germany and UK) and Middle East (Sultanate of Oman) and North Africa (Tunisia).

The international benchmarking is an important source of reflection and action. This tool allows to situate a country in relation to other countries, to learn and discuss the “good practices” implemented, to enlighten the choices of the public and private actors on significant international trends, to transpose measures which have proved their worth abroad and to offer other countries successful experiences implemented in a specified country. In addition, this process also makes it possible to improve knowledge of the specific needs of certain countries and thus to put in place important policies.

The choice the concerned countries was based on the geographical repartition and their different and interesting experiences on sewage sludge management.

RESULTS AND DISCUSSION

NATIONAL PROGRAM OF SANITATION AND SEWAGE SLUDGE MANAGEMENT ISSUE

The sanitation sector in Morocco has until 2005 accounted a very long delay and hasn’t been included in the State priority list. This situation of inadequate collection and treatment of wastewater has generated negative health and environmental impacts. To respond to this situation and catch up in this area of sanitation, the Moroccan State initiated the National Liquid Sanitation Program (PNA) in 2005, with the objective of contributing to the increase in wastewater collection and treatment rates with a total investment cost of 43 bln dirhams (4 bln Euros) until 2020. The operational objectives of the PNA are to achieve an overall connection rate to the sewerage network in urban areas of 75% by 2016, 80% by 2020 and 90% by 2030, and reach a volume of treated wastewater of 50% in 2016, 60% in 2020 and 100% in 2030. The 330 cities and urban centers concerned will ultimately total about 10 mln inhabitants [DGCL 2017; MEMEE 2015].

In order to achieve these objectives, all the actors involved in the field have intensified efforts. Indeed, the current balance is remarkable; up to the end of 2016, the PNA has achieved a connection rate in urban areas of 75% and wastewater treatment rate of 45% instead of 7% in 2006 [DGCL 2017].

Since 2005, many wastewater treatment plants (WWTP) have been constructed and, as shown in Fig. 1, the evolution per year of the number of WWTP operating in Morocco was significant.

The remarkable development of sanitation in Morocco has inevitably induced the production of sludge generated from municipal sewage treatment plants in increasing quantities.

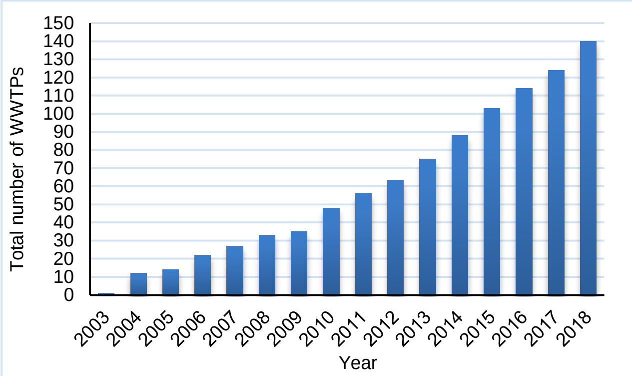

Fig. 1. Total number of wastewater treatment plant (WWTP) operating in Morocco; source: own elaboration based on: MEMEE [2018] and SWIM H2020 SM [2018]

Consequently, the problem of sludge management has become persistent and worrying and encourages the implementation of a sustainable strategy so as not to compromise the initial program of liquid sanitation.

As illustrated in Figure 2, the rate of production of sludge from WWTP in Morocco is quite rapid and the production will reach in 2020 more than 110 t DM (dry matter).

The destiny of sludge from sewage treatment plants is one of the major issues in the management of the sanitation

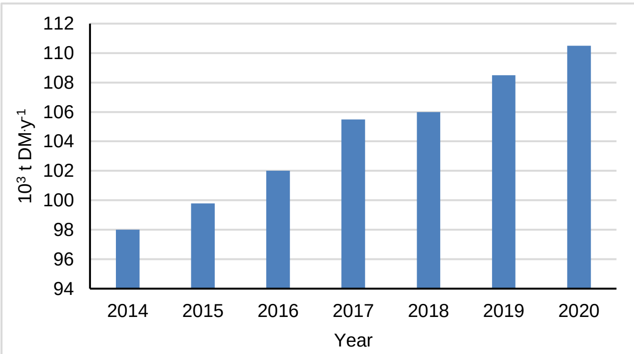

Fig. 2. Current and future state of sewage sludge production in Morocco; source: SOUDI [2018]

service. The increasing volumes of treated wastewater necessarily lead to an increase in the quantities of sludge generated at a time when institutional and regulatory issues in the management of sludge remain inadequate, hindering their recovery and disposal. This situation is a constraint on the sustainability of sanitation projects. In the absence of sludge disposal options and in the objective to reduce its production, the sludge is accumulated in treatment basins (in the case of lagoons treatment plant) or left recycling longer than necessary in treatment reactors (in the case of activated sludge treatment plant), which would significantly reduce the treatment performance. Furthermore, the sludge is eliminated for many cases in the vicinity of the WWTP, as illustrated in Photo 1, showing the produced sludge is stored directly on the site reserved for the extension of the plant. The environmental impacts and the nuisances generated are important.

Photo 1. Sewage sludge stored near wastewater treatment plant (phot. *A. Ghacha*)

Moreover, it should be remembered that the initial version of the PNA did not include the sludge component, and it was only after three years that its strategic review was carried out to include, among others, this component.

Immediately after, and in order to anticipate the problematic sewage sludge management, the State Secretariat for Water and Environment (Fr. Secrétariat d'Etat Chargé de l'Eau et de l'Environnement – SEEE) started in 2008 studies for the development of a national strategy for sewage sludge management. However, the implementation of the recommendations of this strategy is not yet concretized on the ground. Apart from a few isolated and insufficiently consistent initiatives (realization of some pilot projects, initiative for the establishment of a draft decree for sewage sludge recovery), which have failed for most of the time, the past period can be described as a near-empty period or as a period of learning and awareness of the urgency of setting up sludge management solutions adapted to different situations [SOUDI 2015].

STATUS OF SEWAGE SLUDGE MANAGEMENT IN MOROCCO

Study of the National Sludge Management Strategy

In its initial version, the PNA did not integrate the sludge component, but during its strategic review in November 2007, with the assistance of donors, proposals for readjustment of a number of components and implementation mechanisms have been formulated. Among these readjustments, the need to develop a national sludge management strategy was recommended.

It is in this context that the State Secretariat for Water and Environment (SEEE) started in 2008 studies for the development of this strategy. The studies had the following objectives [MEMEE 2010]:

- diagnosis of the current situation with projections of sludge production,
- analysis of international experiences,
- proposal for potential treatment, recovery and elimination channels adapted to the Moroccan context,
- proposal of an organizational, institutional and sludge management system,
- proposal of a plan of action of accompaniment to the implementation,
- elaboration of a manual of good practices of management of the sludge of the sewage treatment plants in Morocco.

According to these studies, three important destinations are to be promoted in Morocco for non-hazardous sludge and are reported below in order of preference:

- green recovery: agricultural reuse, rehabilitation of degraded sites, reuse in silviculture and forest nurseries and ornamental plants,
- recovery in cement plants,
- combined landfill or mono-landfill, depending on the situations and constraints; it is clear that mono-landfill is a solution of last resort.

The cost of implementing the strategy was estimated at 70 mln dirhams [MEMEE 2010].

As mentioned before, the implementation of the recommendations of this strategy is not yet concretized on the ground. Apart from a few isolated and insufficiently consistent initiatives (the realization of some pilot projects, the initiative of establishment of a draft decree for sewage sludge recovery), which have failed for most of the time, the past period can be described as a near-empty period or as a period of learning and awareness of the urgency of setting up sludge management solutions adapted to different situations [SOUDI 2015].

Current destination of sewage sludge in Morocco

Morocco, like the countries of the Middle East and North Africa (MENA) region, is not yet advanced in terms of implementation of sludge disposal and recovery methods. The sludge is thus accumulated in the vicinity of WWTP, causing a nuisance to residents and the surrounding environment or, in most cases, where possible, is dumped in landfills. At times, the operators are forced to leave the sludge “masked” in the treatment basins, which is reflected by a significant loss of the purification performance of the treatment plant. This situation has been well and truly lived in Tunisia [ONEE, FAO 2016].

The results of the data analysis of a survey conducted in 2005 at 34 WWTP points out that in 56% of the WWTP surveyed, the sludge produced is essentially naturally dried and transported to public landfills, and 6% pay royalties for the municipality. 24% of WWTP evacuate sludge in drying beds waiting for a convention with zero fees with the municipality for landfill and a framework contract for sludge transportation. 10% did not report anything about the final destination of the sludge.

It is necessary to note that the olfactory nuisances emanating from the sludge stored near the treatment plant and the remoteness of landfills are two major problems facing 80% of WWTP.

As for the national experience in the field of sludge recovery, including reuse in agriculture, considered the most adapted to the Moroccan case, it should be noted that this route remains undeveloped and insufficiently explored. In addition, there are currently no agricultural recovery projects carried out on a representative scale and with success. However, in order to generate a technical and normative reference, some pilot projects have been carried out and aimed to subsequently generalize the agronomic recovery of sludge at the national level and to stimulate reflection on the establishment of an appropriate regulatory and institutional arsenal for this sector and concerted with stakeholders.

Sludge spreading pilot projects have taken place in Grand Nador and Dar El Gueddari. However, although these tests were successful mid-term in terms of sludge quality, the experiences were interrupted by the disengagement of project participants. In addition, a pilot test of co-composting sludge generated by the WWTP of M'Zar with other organic waste was carried out in Agadir. The quality of the compost obtained was in accordance with the European standard NFU 44-095, and it emerges from this experiment that the reuse of composted sludge is technically and normatively controllable [SOUDI 2015].

Concerning the energy recovery from sewage sludge, it is little developed in Morocco. Biogas cogeneration from sludge is done at a few stations. For example, at the Marrakech WWTP, which produces an average of 71 Mg of sludge at 31% dryness, 800 Nm^3 per day of biogas is produced and used for the cogeneration of electricity for the plant. At Khouribga WWTP, the production of the biogas is about 2600 Nm^3 per day, which is used to satisfy 100% of the thermal energy need of the plant and 30–40% of its electrical energy need. At WWTP of Fez, 50% of its energy need is ensured by recovered biogas. 22 mln $KWh \cdot year^{-1}$ of electricity is produced by capturing 15 000 $m^3 \cdot day^{-1}$ of biogas.

Landfilling, internationally described as an unsustainable option and last resort, seems to be the trend in Morocco today. In fact, most sanitations operators prioritize it until the technical, institutional and regulatory standards relating to sludge management are put in place. Recently, however, there has been a blocking situation caused by the reluctance of many municipalities to receive sludge in their landfills (huge quantities of sludge, olfactory nuisances, overproduction of lixiviate, landfill saturation). Moreover, the operators, in case their sludge is accepted in the landfills, are sometimes obliged to pay negotiated and non-statutory fees to the municipalities.

As will be mentioned below, the sludge status in Morocco is not clearly defined and can promote this lack of synergy between the sludge producers and municipalities.

Facing this impasse situation encountered in sewage sludge disposal and/or recovery, Moroccan operators of the wastewater facilities have recently started looking for solutions to reduce the quantities of sludge produced in waste water treatment plants by targeting high degrees of compression of the sludge.

In fact, several projects (in Nador, Hoceima, Dakhla, Fez and Marrakech) are underway concerning the solar sludge drying system and aimed to increase the sludge dryness rate from 20–30% to 60–80%. The implementation of these sludge-dewatering projects will considerably reduce the volume of the sludge produced in the plants and consequently reduce the cost of an eventual sludge transport. In addition, dewatering makes the sludge more stable and more suitable for any recovery.

IDENTIFICATION OF THE CONSTRAINTS HAMPERING THE SLUDGE RECOVERY AND DISPOSAL IN MOROCCO

Technical and environmental constraints

The majority of the recovery and/or disposal methods are constrained by problems linked to the quality of the sludge produced in treatment plants.

Currently, the sludge produced in the majority of WWTP is characterized by drynesses not exceeding 25%. This dryness is not appropriate for the majority of recovery and/or disposal methods for the following reasons: transport over cost, overproduction of leachate in the event of landfill, high moisture content of the sludge does not encourage cement plants to receive them in their furnaces.

For land application in agriculture, there’s a difficulty in guaranteeing the quality of the crops applied in the case of agricultural reuse [MEMEE 2010]. In addition, the quality of the sludge is both an advantage (presence of residual nutrients, such as nitrogen and phosphorus) [ANTONKIEWICZ *et al.* 2019] but also a source of risk (heavy metals, presence of pathogenic germs) [ANTONKIEWICZ *et al.* 2018].

Additionally, the sludge generated by the WWTP is not always in the immediate vicinity of the recovery zones (cement plants, agricultural zones), which requires transport of the sludge for a long distance.

Last but not least, the demand in time for sludge recycling is not the same as the logic of availability. In fact, the sludge production is quasi-regular in daily frequency and in large quantities (case of activated sludge plant), while the demand is not regular.

Regulatory constraints

The situation characterizing the crucial problem related to sludge management is a direct consequence of the legal deficiencies. In particular, there is a lack of clarity in the status of sludge and an absence of standards for recovery and/or disposal and the conditions governing the use of sludge, in particular, in the case of spreading options.

The two texts allowing the assessment of the conditions for the management of sewage sludge are: firstly, the Decree No. 2-07-253 (18 July 2008) on the classification of waste and fixing the list of hazardous wastes (Annex I, code 19), which classifies sludge as "hazardous waste". This decree was adopted pursuant to the Law No. 28-00 on waste management and disposal [Loi n°28-00]. There is no standard reference for determining the thresholds for judging the assimilation of waste into household waste. For this reason, sludge is not accepted by many municipal landfills or accepted with payment of a concerted and non-regulatory fee. Secondly, treatment plants have the status of classified installations. Thus, their construction is subject to legislation relating to the Dahir of 25 August 1914 on the regulation of unhealthy, disturbing or dangerous establishments and the Dahir No. 1-03-60 concerning the promulgation of the Law No. 12-03 relative to the studies of impact on the environment.

The regulations governing the sludge generated from of WWTP remain unclear and incomplete.

Institutional and organizational constraints

The absence of a leadership organization that takes charge of piloting the management of the sludge of WWTP is one of the major constraints hampering the development of this sector. Indeed, the diversity and multiplicity of the actors constitute a real difficulty in defining the roles of the stakeholders. This multitude of actors and the overlapping of their responsibilities make it difficult to identify those in charge of planning, project management and operation related to this sector.

In Morocco, although the organic law stipulates that the management of the sanitation service falls within the competence of the municipalities, the majority of the latter, after delegation of their sanitation services to operators of the domain, disengage itself from all its responsibilities concerning these services, including the sludge sector, and put all the responsibility of sludge elimination on the operators. Indeed, since the delegated management agreements do not specify the method and the cost of sludge management in its clauses, the operator is always the only one to take the initiative to find sludge elimination solutions, faced with the reluctance often of the municipalities to accept this sludge in their landfills.

It is noteworthy that landfill has to be the last option to be considered in sewage sludge elimination for many reasons (the volume of sludge, the high operational cost of landfills, environmental impacts: leachate, odours etc.). Nevertheless, in a transient way, the process of landfill remains inevitable [MEMEE 2010].

Economic and financial constraints

One of the major problems of sludge management is the high cost of sludge treatment, which is often more than 50% of the total treatment cost of municipal wastewater [LENS*et al*. 2004].

In order to understand the economic and financial stakes involved in sludge management (recovery and/or disposal), the following questions should be asked: Who pays the investment after having clearly opted for a sludge recovery option? Who pays for the infrastructure operation? Who pays the expenses inherent in the management of this sector? And finally, who pays the expenses of quality control to the monitoring of the environmental and sanitary impact of an eventual sludge recovery?

To date, all these questions remain unanswered due to the lack of a clear regulation governing the sewage sludge sector.

INTERNATIONAL SEWAGE SLUDGE MANAGEMENT

European countries

General information. In 2005, the annual sewage sludge production in EU-27 was estimated to be 10.9 mln t DM. Indeed, the implementation of the urban waste water treatment (UWWT) Directive 91/271/EC forced EU-15 countries (old Member States) to improve their wastewater collecting and treatment systems. As a result, an almost 50% increase in annual sewage sludge production in EU-15 was noticed, from 6.5 mln t DM in 1992 to 9.8 mln t DM in 2005. On the other hand, the annual sewage sludge production in EU-12 (new Member States) was estimated to be 1.1 mln t DM in 2005. The implementation of UWWT Directive 91/271/EC by the new EU-12 members will certainly increase production to reach 13 mln t DM in 2020 [KELESSIDIS, STASINAKIS 2012].

As shown in Figure 3, sewage sludge production seems to be differentiated significantly between different European countries. Germany is the highest producer of the sludge, followed by the United Kingdom, Spain and France.

Regarding sewage sludge management, as shown in Figure 4, the main methods of sewage sludge management in the EU remain agricultural use and incineration. Even though approximately about 40% of the total sludge produced in the EU is used for agriculture purposes, the individual EU countries are very different in terms of the amount used for agriculture. Some EU Members have

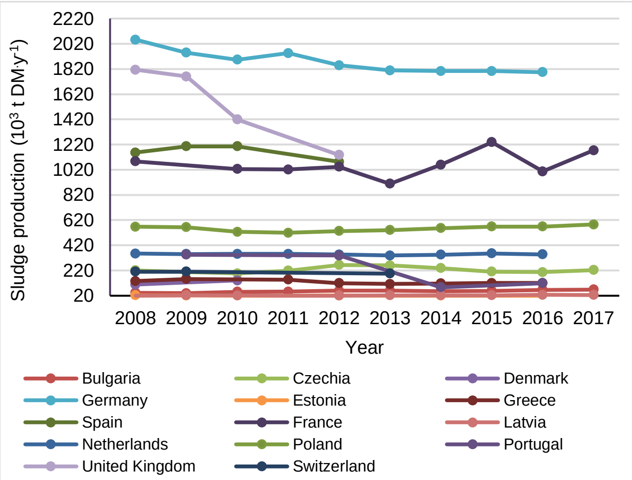

Fig. 3. The production of sewage sludge in selected countries of EU; source: own elaboration based on: Eurostat [2020]

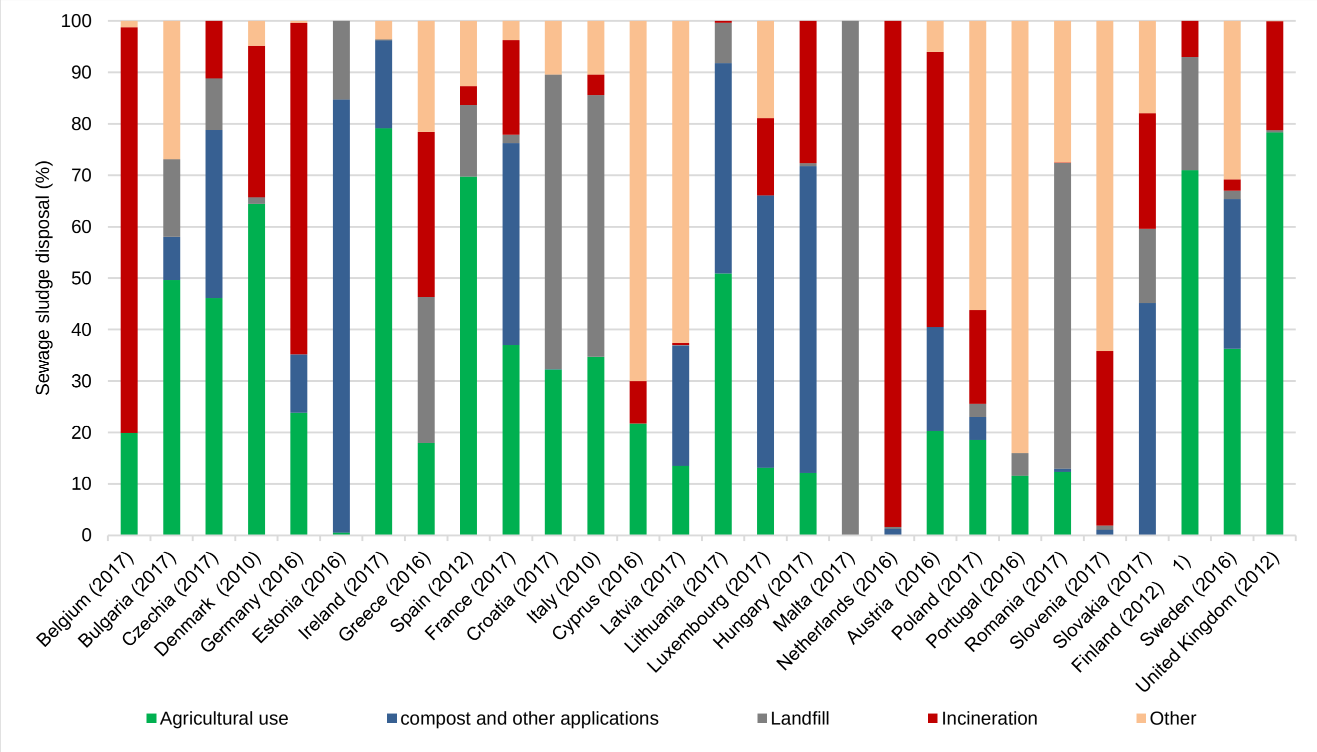

Fig. 4. Sewage sludge disposal routes in the EU countries; source: own elaboration based on: Eurostat [2020]
[1)] data according to: COLLIVIGNARELLI *et al*. [2019]

adopted stricter limit values for contaminants than those contained in the Sewage Sludge Directive. Other countries (Austria, Hungary, and the UK) introduce limit values for additional heavy metals in the soil – Styria (Austria Lander) provides limits for molybdenum (10 mg·kg^{-1} DM) and cobalt (50 mg·kg^{-1} DM); Hungary for molybdenum (7 mg·kg^{-1} DM), cobalt (30 mg·kg^{-1} DM), and selenium (1 mg·kg^{-1} DM); and the United Kingdom for molybdenum (4 mg·kg^{-1} DM), selenium (3 mg·kg^{-1} DM) and fluoride (500 mg·kg^{-1} DM) [COLLIVIGNARELLI *et al*. 2019].

Several Member States are taking into consideration the environmental risk after applying sludge to agricultural land and have even banned its use, while others use it widely and are still improving sludge management. In Belgium, Denmark, Spain, France, Ireland and the United Kingdom, the amount of sludge used for agriculture was more than 50% in 2010 [KACPRZAK *et al*. 2017]. However, in other countries, for instance, in Finland and Belgium, <5% is used for agricultural purposes. In Greece, Netherlands, Romania, Slovenia and Slovakia, sludge is not used in agriculture, especially because of its strict national regulations, which include restrictions in terms of the maximum annual load of heavy metals on agricultural land [COLLIVIGNARELLI *et al*. 2019]. In Poland, a gradual decrease in landfilling of sewage sludge and an increase in their thermal conversion has been observed. In non-EU countries, such as Norway and Switzerland, larger amounts of sludge are applied in agriculture. According to the Directive1999/31/EC, Norway had an official target to recycle 60% of sewage sludge to farmland, which has already been reached in 2008, as 80% of the sludge was recycled to farmland or green areas. Switzerland, in contrast, has banned the use of sewage sludge on farmland since 2005 [KACPRZAK *et al*. 2017] because of the fear of the distribution of mad cow disease (bovine spongiform encephalopathy – BSE), together with the constantly increasing pollution of sludge by persistent organic pollutants (POP) [MORF 2012].

Regarding the cost of the different strategies of sewage sludge management, in Europe, the average costs of different wastewater treatment and disposal of non-treated sludge is 160–210 EUR·t^{-1} DM. In the case of the use of dewatered sludge in agriculture or forestry, including incineration with household waste or reclamation of degraded areas, the costs increase to about 210–300 EUR·t^{-1} DM [JAKOBSSON *et al*. 2012].

According to JAKOBSSON*et al*. [2012], details concerning the average costs of different strategies of management of sewage sludge in all European countries are as follow (EUR·t^{-1} DM) :

– agriculture: raw sludge and partly dewatered sludge (15–25% ds) : 160, dry sludge : 210,
– forestry – 240,
– composting – 310,
– incineration – 315,
– reclamation of landfills and degraded areas – 255,
– landfill – 255.

According to the urban wastewater treatment (UWWT) Directive 91/271/EEC, the collection and treatment of municipal wastewater are compulsory for agglomerations with a population equivalent to more than 2,000. The sludge reuse is encouraged and final disposal to surface waters has been forbidden since 31.12.1998. The implementation deadline for the UWWT Directive was 2005 for the older EU-15 Member States and 2015 or 2018 for the countries that joined the EU after 2004 [KELESSIDIS, STASINAKIS 2012].

On the other hand, Decision 2001/118/EC of the Council of the European Communities (CEC) enlist sludge in non-hazardous wastes, whereas, according to European policy, the following waste hierarchy shall apply as a priority order in waste management: (a) prevention, (b) preparing for reuse, (c) recycling, (d) other recovery, e.g., energy recovery, (e) disposal. Based on these principles, the Landfill Directive 99/31/EC prohibited landfilling of both liquid and untreated wastes and set restrictions as well as quantitative targets for biodegradable municipal solid wastes (such as sewage sludge) that are disposed of in landfills. According to these, a reduction of 50% and 65% of produced solid waste by the years 2013 and 2020 should be achieved, respectively [KELESSIDIS, STASINAKIS 2012]. Apart from the above, national legislation of some Member States have set very strict limits for the organic matter or total organic carbon (TOC) contained in sludge (e.g., Germany, Austria, Netherlands), practically prohibiting sludge landfilling [KELESSIDIS, STASINAKIS 2012].

Additional to the above, the main legislative text that refers to sludge management is Sewage Sludge Directive 86/278/EEC, which describes beneficial sludge (bio-solids) use on soils. This directive seeks to encourage safe use of sewage sludge in agriculture and to regulate its use in such a way as to prevent harmful effects on soil, vegetation, animals and humans. Among others, it specifies rules for the sampling and analysis of sludge and soils, sets out record-keeping requirements and limit values for concentrations of heavy metals in sewage sludge and soil. The Member States are able to apply stricter restrictions than those determined in Directive 86/278/EEC, and this is observed in several cases. Specifically, 16 out of 27 EU countries (63%) have set more stringent national requirements for heavy metals concentrations in sludge compared to EU Directive provisions, whereas 10 out of 27 countries (37%) have set stricter limit values for the concentrations of heavy metals in soil. There is a wide variation in national limit values for heavy metals, even between similar geographical areas, such as the Nordic or Baltic countries. In most cases, Nordic countries (Finland, Sweden, Denmark and the Netherlands) have set the lowest limit values. On the other hand, except for France, Malta and Slovenia, Mediterranean countries have adopted the limit values that are proposed by the EU Directive [KELESSIDIS, STASINAKIS 2012].

Concerning the disposal of untreated sludge in soil, most European countries have prohibited it. In some cases, specific obligations for treatment have been set, such as biological or chemical stabilization before reuse, while there are a few countries that allow the use of untreated sludge under certain authorized conditions (e.g., France, Sweden and Estonia). Finally, the use of sludge in forests, mines and green areas has been prohibited in several countries [KELESSIDIS, STASINAKIS 2012].

In terms of incineration and co-incineration, two European directives have been elaborated: Directive 89/369/EEC and Directive 89/429/EEC. These directives have been revised by Directive 2000/76/ECC of 2008 (modified in 2008) concerning waste incineration. This directive has defined threshold values for atmospheric emissions resulting from the incineration [SOUDI 2015].

Germany. Germany generates the largest amount of sewage sludge in the EU, with approximately 1.8 mln t of sewage sludge dry mass utilized or disposed of in 2016. During that year and as reported in Figure 5, approximately 64% of this sludge was incinerated through co-incineration or mono-incineration (including gasification installations), 24% were applied to farmland, and 11% were managed via other methods, including composting and landscaping [CLAUS-GERHARD 2018].

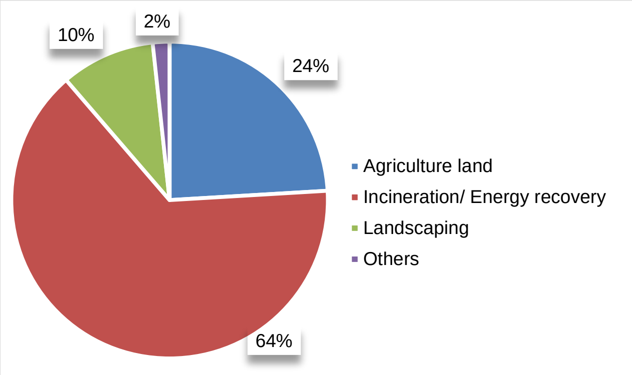

Fig. 5. Sewage sludge routes in Germany in 2016;
source: own elaboration based on: CLAUS-GERHARD [2018]

In 2010, the disposed quantity was more than the produced; this difference computed for Germany can be explained by the importation of sewage sludge from other European countries, Scandinavia, in particular [PELLEGRINI *et al*. 2016].

Table 1 illustrates the various sewage sludge management methods in Germany. Between 1991 and 2009, thermal disposal of sewage sludge rose from 9.0 to 52.5%, while the use of sewage sludge for landfill declined from 42% to practically zero, owing to the ban on the use of sewage sludge for landfill that took effect on 1 June 2005. The use of sewage sludge for landscaping has likewise declined, from 628,550 TDM in 1995 to 282,455 TDM in

Table 1. Sewage sludge management in Germany in 1991–2010

Year	Dry solids use (%)			
	landfill	farming	landscaping and others	incineration
1991	42.0	28.0	2.7	9.0
1995	16.0	39.0	15.5	9.0
1998	8.3	31.7	28.9	16.0
2001	6.6	31.1	26.5	22.8
2004	3.5	27.8	24.1	31.5
2007[1)]	0.2	28.8	21.6	49.4
2008	0.1	28.6	18.8	52.2
2009	0.0	30.1	17.3	52.2
2010	0.0	30.0	16.8	53.2
2011	0.0	29.1	16.2	54.7

[1)] No. 100% tallies available prior to 2007 owing to a change in statistical gathering methodology.
Source: own elaboration based on: WIECHMANN *et al*. [2013].

2009. The use of sewage sludge for farming has remained relatively constant over the years [WIECHMANN *et al*. 2013].

The most abundant form of sewage sludge management in Germany is thermal processing; anaerobically digested sludge is incinerated at mono-incineration plants, coal-fired power plants, cement plants, and at certain waste incineration facilities [WIECHMANN *et al*. 2013].

Germany has approximately 20 sewage sludge mono-incineration plants with an aggregate combustion capacity of 580 t of dry solids per year and seven private sector sewage sludge mono-incineration plants with an aggregate combustion capacity of 830 thous. t of original sewage sludge per year. Germany has several pilot and full-scale gasification facilities in operation. Aside from incineration in mono-incineration plants, the sludge is also disposed of through co-incineration, which occurs mainly as coal-fired power plants, waste incineration plants, and cement plants [WIECHMANN*et al*. 2013].

Regarding sewage sludge reuse in agriculture, it is subject to federal legislation, with three states opposed to the use of the sludge and eleven states in favour. Germany has established a liability compensation fund to remedy problems that might arise from land application. The fund, which is not linked to any quality management system, was started voluntarily by some of the leading operators and later taken over by the federal government [EDI 2017; EVAN 2012].

One of the important factors conditioning the reuse of sludge in agriculture is the concentration of heavy metals in this sludge. As shown in the end, Germany is a major supplier of incinerator technology. Considerations for the future of Germany's sewage sludge management program include transitioning from agricultural use of the sludge to the exclusive use of mono-incineration in conjunction with energy and phosphorous recovery, in an aim to avoid soil substance and contamination risks and eliminate Germany's dependence on imported phosphorous [WIECHMANN *et al*. 2013].

One of the important factors conditioning the reuse of sludge in agriculture is the concentration of heavy metals in this sludge. As shown in Figure 6, Germany has made

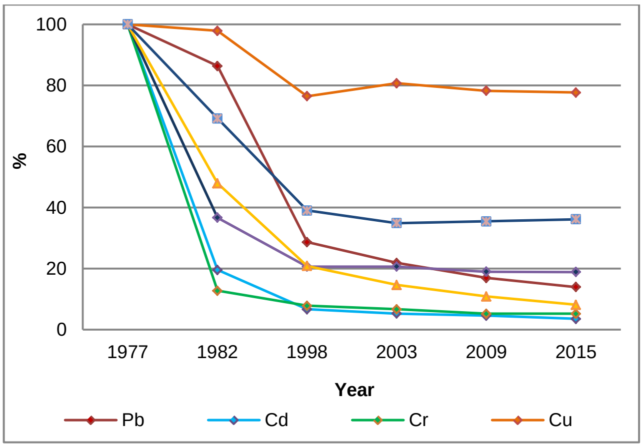

Fig. 6. Development of the heavy metal concentrations in sewage sludge (%); source: own elaboration based on: German Environment Agency [2018]

enormous efforts to reduce these concentrations, either by reducing the consumption of some products by the population, or by advanced wastewater treatment.

United Kingdom. The United Kingdom (UK) is one of the pioneers in the treatment and recycling of wastewater; there are 7,078 sewage treatment plants in England and Wales, 10,814 sewage treatment plants and community septic tanks in Scotland and Northern Ireland, and 98% of urban and rural households connect to the UK's sewerage service [GOV.UK 2015].

The UK beneficially reuses most of its sewage sludge in agricultural land application as it is recognized as the best practicable environmental option in most circumstances by the government.

Almost 1.4 mln t DM of sludge was produced in 2008 in the UK, of which 77% was recycled to agriculture land as shown in Figure 7. A further 16% was incinerated (mostly with energy recovery) [Water UK 2010].

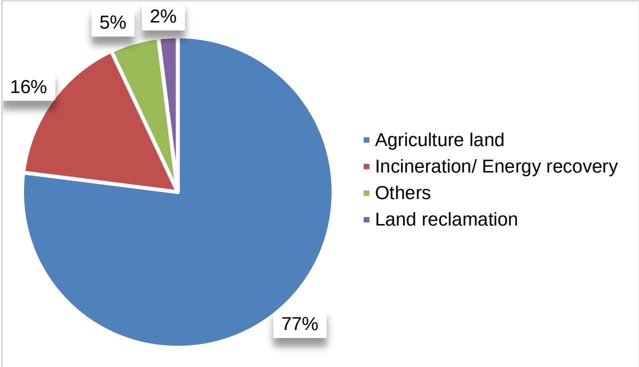

Fig. 7. Sewage sludge routes in the UK in 2008; source: own elaboration based on: Water UK [2010]

During the last decade, the UK has undergone a shift from energy-intensive processes with high carbon footprints (incineration, thermal drying, and lime stabilization) to energy-producing wastewater processing using advanced digestion paired with sludge agricultural land application [EDI 2017; PANTER, BARBER 2017].

A combination of strict financial regulation, high energy costs, and renewable energy incentives have led the UK Water Industry to invest heavily in advanced anaerobic digestion. The UK has the highest proliferation of thermal hydrolysis plants anywhere in the world (21 full-scale facilities) that treat more than a quarter of sludge production, 1,500 t DM per day, and generate 60 MWs of electrical energy continuously [EDI 2017; PANTER, BARBER 2017]. They have developed sewage sludge centers where anaerobic digestion of the sludge is centralized, which has made sludge pretreatment more affordable, increased solid loads at treatment plants promoting energy self-sufficiency through biogas capture, and has provided greater ability to enhance product quality. When all current development projects in the UK are complete, 92% of all sewage sludge will be digested with captured biogas used in combined heat and power generation. Currently, nearly all digested sludge is applied to farmland. Almost all thermal dryers and incinerators have been decommissioned, and lime stabilization is now rare [EDI 2017].

Countries of Middle East and North Africa

Tunisia. In 2017, the number of operating wastewater plants in Tunisia are 119 plants, producing a volume of dry sludge of 175,000 $m^3 \cdot y^{-1}$. (Dryness ranging from 18% to 70% with 53% produced by the WWTP of Grand Tunis). Tunisia is, therefore, faced with the challenge of finding secure solutions for the recovery and/or disposal of sludge generated from wastewater treatment (24% is landfilled, 35% is stored in WWTP sites and 41% stored in National Office of Sanitationsites – Fr. Office National de l'Assainissement – ONAS).

Until 1997, stabilized sewage sludge has been used as fertilizer in agriculture. It was common to sell sludge for a symbolic price (less than 2 dinars per cubic meter on the site of the treatment plant); it was in great demand and did not remain in stock at treatment plants. However, sludge reuse practices, uncontrolled and not monitored by an official body or institution to verify the impacts of this open reuse, were not subject to a formal regulatory framework.

In 1997, the Ministry of Public Health (Fr. Ministère de la Santé Publique) decided to ban the use of wastewater sludge, even if it is well-treated, pending the establishment of a Tunisian regulation to this effect. Since then, the sludge is no longer reused in agriculture and is landfilled to the nearest if there is, otherwise this waste sludge is stored near treatment plants [HORIZON 2020].

Faced with a sudden and very difficult situation, The National Office of Sanitation (ONAS) in 1998 took steps in collaboration with the International Center for Environmental Technologies of Tunis (Fr. Centre International des Technologies de l'Environnement de Tunis – CITET) to set up the usual procedure to develop a standard for the use of municipal sewage sludge. After a work of the technical commission, created for this purpose, the norm 10 620 was born in December 2002 [HORIZON 2020].

The standard alone did not allow the use of sludge. It was necessary to wait for the arrival of:

– the specifications fixing the conditions of use of the sludge by the agricultural operator, approved by joint decree of the Minister of Agriculture and the Hydraulic Resources (Fr. Ministère de l'Agriculture et des Ressources Hydrauliques) and the Minister of the Environment and Sustainable Development (Fr. Ministère de l'Environnement et du Développement Durable) of 29 December 2006;
– The Decree No. 2007-13 of 3 January 2007 laying down the conditions and methods for sewage sludge management for use in agriculture.

However, as illustrated in Table 1 and Figure 8, even with the arrival of these standards, the application was only timid (spreading concerns just a small area and a few farmers) because of the regulatory constraints in their practical application.

Currently, the problem of sewage sludge management is considered a priority in Tunisia. A study program proposes to develop sludge management master plans by region (Grand Tunis region, North region, South region and Central region). The completed studies recommended three different types of sludge use according to the characteristics of the concerned area: i) fertilization (green sector), ii) combustion cement production (red sector) and iii) storage transport to a controlled landfill (brown sector).

Table 1. Sludge recovery indicators in the agricultural sector in Tunisia for the year of 2017

Specification	Quantity/value
Volume of produced sludge (dry)	175,000 $m^3 \cdot y^{-1}$
Volume of naturally dried sludge	55,000 $m^3 \cdot y^{-1}$
Volume of mechanically dried sludge	120,000 $m^3 \cdot y^{-1}$
Quantity of naturally dried sludge with recovery	2,900 t
Number of wastewater plants with recovery sludge	12 plants
Sludge spreading area	400 ha
Number of beneficiary farmers	23 farmers

Source: Office National de l'Assainissement ONAS [2017].

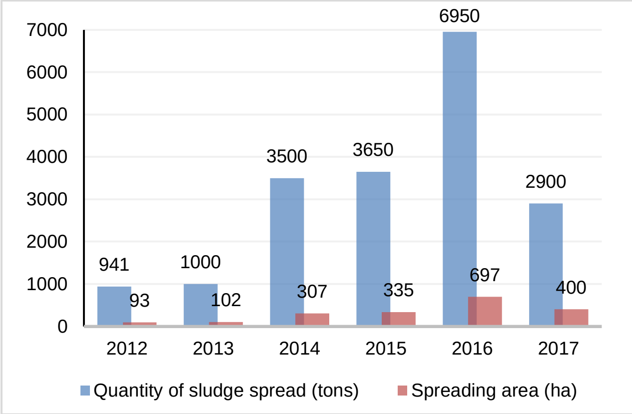

Fig. 8. Evolution of sludge spreading on agricultural farms in Tunisia; source: ONAS [2017]

Existing standards concern only, for the moment, the first sector (green sector). Studies are currently underway for the development of the three sectors, especially the development of regional sludge management master plans.

In conclusion, the situation in Tunisia regarding sewage sludge management requires a certain number of clarifications. The hesitations of the State (authorization, prohibition and then new authorization of reuse in agriculture) did not facilitate the settlement of the situation. Even though several pilot sites have been set up and master plans are being discussed, it seems necessary to clarify a number of institutional points, such as the role of managers and users as well as their interrelationships, their fields of application action and their responsibilities [HORIZON 2020].

Sultanate of Oman. The experience of Sultanate Oman is quite interesting in the field of sewage sludge management. In fact, in 2010, the operator of the wastewater facilities in the Muscat Governorate, launched an initiative to produce a marketable compost from the sewage sludge, which is used for agricultural activities.

With the goal of developing, designing, implementing and managing wastewater projects in Muscat. The operator is steadily implementing one of the world's largest modern wastewater projects. It was assigned in 2014 by the government to implement and manage all wastewater projects and assets in all governorates except Dhofar, due to its distinctive accumulated expertise in the field of wastewater treatment. It will be responsible for the planning, development, implementation, management, operation and maintenance of all wastewater assets and facilities in all governorates except Dhofar. It has taken over the role of the Ministry of Regional Municipalities and Water Resources, which was operating in 44 Wilayats with varying populations.

The capacity of the 11 sewage treatment plants currently in Muscat is 17,092 $m^3 \cdot day^{-1}$. A further 14 projects are being implemented currently in Muscat. The lengths of the total sewage network in the Muscat Governorate is currently 1,874 km, and the length of the treated water network in Muscat Governorate is about 814 km [Haya Water 2017].

One of the economic principles adopted by this operator in Muscat in its operations is the promotion of the added value of its products. Hence, it has launched its natural compost factory as a continuation of its important environment-friendly productions.

The composting plant has an area of 60,000 m^2 and is located in Al Amerat (Al Maltaqa), which belongs to the Muscat government. Composting is a biological process that depends mainly on the activity of naturally occurring microorganisms.The factory converts the sludge generated from wastewater treatment and mixes it with other organic materials, such as the remnants of trees and green grass, using an open air piles technology to produce a marketable compost with high-quality specifications identical to international environmental specifications [JAFFAR ABDUL KHALIQ*et al*. 2017]. This compost is widely used on farms and home gardens, thus contributing to the elimination of one of the direct pollution sources that release greenhouse gases and has an impact on world climate [Muscatdaily.com 2016].

The plant also includes a new laboratory that is equipped with the best techniques that are used on product testing and ensure its conformity with the approved standards before launching it on the market with the supervision of a number of experts in this field. In addition, Haya Water Central Laboratory collects and analyses samples of the final product of the compost to ensure compliance with the approved standards [Muscatdaily.com 2016].

According to the journal of Oman Daily Observer, farmers are praising the quality of the organic compost and urging other farmers to use it for cultivation. Saif bin Ali bin Saif al Deghishi, from the Wilayat of Samayil, said, “Through my experience of using this compost for several years, I’m confident this fertiliser has many advantages, including the fact that no weeds grow when using it, and it preserves the soil’s moisture”. “It is certain that when using this compost, some vegetables such as zucchini, pumpkin and other crops cannot be harvested for several reasons, including the lack of suitable soil for growing such crops. However, I have observed that when composting the land with it, the harvest of these vegetables increased.” [Oman Daily Observer 2017].

Saif al Deghishi uses Kala to grow tomatoes, onions, garlic and radish, and “I always get a good harvest. I urge other farmers to use it, especially since it is an Omani product.” Abdul Rahman bin Zahran al Abri from the Wilayat of Bahla said this compost is very beneficial for agriculture, and weeds do not grow when fertilizing the soil. “I have found it one of the best fertilizers I have tried, especially with palm trees.”

The operator of the wastewater facilities in the Muscat has declared that since the establishment of the composting plant, the production has been continuously increasing, with total sales exceeding 400,000 bags in 2016. Since the commencement of commercial production in 2011, the plant has produced more than two million bags [Oman Observer 2017].

The composting plant has been accredited by the United Nations Development Program (CDM). It is the first organic fertilizer plant in the Middle East to receive such a certificate. The operator, in collaboration with Sultan Qaboos University, conducted scientific research from 2013 to 2015 to study the effects of its compost on crops. The results proved that there is no accumulation above the normal level in terms of the concentration of heavy elements or harmful germs in the soil. The study indicated it increases the fertility of the soil and improves the ability of the soil to retain water. It also provides plants with many types of nutrients, which increases the quantity and quality of various agricultural crops [Oman Observer 2017].

One of the important elements that have contributed to the success of sludge recovery management in the Sultanate of Oman is the existence of clear national regulations governing sludge management. In 1993, the ministerial decision No. 145/93, “Regulations for Wastewater Reuse and Discharge,” was issued and defined the reuse of sludge under certain specifications. In 2001, “The Law on Protection of Sources of Drinking Water from Pollution,” was issued under Royal Decree number 115/2001 and defined the conditions for sewage sludge reuse in agriculture [SEU/MECA 2013].

Learned lessons from the international experiences in sewage sludge management

From the international benchmarking, it is becoming clear that management practices for sewage sludge are not uniform from one country to another. The countries are very different in terms of the quantity of sewage sludge directed to each recovery sector. Some have adopted stricter regulations, leading, in some cases, to the prohibition of certain recovery and disposal options, while others are still open to all options and improve their management of sludge.

The sewage sludge reuse in agriculture, the most dominant, is subject to regulatory constraints stipulating its safety. Indeed, the regulatory framework for the different types of sludge recovery or sludge disposal requires the production of better quality sludge in order to ensure their safety and recovery in secure conditions. However, this option of green recovery remains the most privileged option, being its compelling advantages in terms of agronomic interest, circular economy (return of organic matter to the soil), preservation of soil quality and fight against the greenhouse effect. Indeed, if this option appears the most favoured in the world, it is justified even more for

Morocco given its agricultural vocation, the increasing rate of soil degradation, and the progress of the scourge of desertification [SOUDI 2018].

About landfilling, it is the least desirable option due to the high environmental impacts, i.e. potential groundwater pollution, methane emissions, and aftercare periods of hundreds of years [HAZLEGREAVES 2019].

Regarding the financial side, the cost of the different strategies of sewage sludge management is very high. Indeed, it is estimated that approximately 50% of the costs of operating secondary sewage treatment plants in Europe can be associated with sewage sludge treatment and disposal [KACPRZAK *et al*. 2017].

In the end, in some countries (i.e., UK, USA, Canada), the sewage sludge is named bio-solids. Indeed, the sludge disposal industry had great difficulty in the past convincing the public that an ugly name, such as "sludge, could actually be beneficial". The Water Environment Federation in the U.S. first suggested the use of the term "bio-solids" to designate sludge destined for disposal [SPINOSA, VESILIND 2001].

Recommendations for the promotion of sewage sludge recovery and disposal process

In order to overcome the constraints hampering the sustainable sewage sludge management in Morocco, and to capitalize on the opportunities, a number of priority actions should be implemented.

First, to eliminate the quantities of sludge already stored or being produced the establishment of institutional arrangements and specifications for the implementation of both sectors co-incineration in cement plants and landfilling proves necessary.

As recommended by the study on the sludge management strategy in 2010, it is clear that green recycling of sludge (in agriculture, silviculture and rehabilitation of degraded soils) is the most environmentally friendly option, a sustainable and economically viable solution for Morocco. Indeed, if this option appears the most favoured in the world, it is justified even more for Morocco, given its agricultural vocation, the increasing rate of soil degradation, and the progress of the scourge of desertification. This recovery will also generate economic gains in terms of fertilization and improvement of soil quality and, therefore, their productivity.

Furthermore, the establishment of a sludge management regulation is indispensable. This regulation must clarify the status of the sludge, set the standards of sewage sludge recovery and disposal, and fix sludge storage, transport and reuse specifications.

It is also recommended to assign to the Ministry of Agriculture the role of sponsor in the field of sludge reuse in agriculture and more specifically, the promotion of the demand. This Ministry can also intervene in sludge reuse projects downstream, through the National Office for Food Safety (Fr. de l'Office de Sécurité Sanitaire des Produits Alimentaires – ONSSA), which consists of an institutional mechanism for integrated and modern control of food products [LÉGER, NBOU 2010; MEMEE 2010].

For the sociocultural and communication component, promoting the recovery of sludge (spreading, incineration, etc.) requires raising awareness amongst the beneficiaries of the stakes expected by these sectors (economic and financial gains).

To draw up a guide to good practices for sewage sludge management, pilot projects need to be conducted to evaluate each sludge management route (co-incineration, composting and green recycling, etc.) with the different sludge pre-treatment options and in different contexts (the size of WWTP, climate, the agricultural context, the proximity of cement plants, etc.). In this sense, it is also necessary to strengthen the partnership with international institutions and organizations for gathering relevant feedback on sludge recovery and disposal.

Last but not least, in order to reduce sludge volumes and to achieve overall cost efficiency for recovery and disposal, advanced sludge drying systems need to be considered. If the solar greenhouse drying system appears most favoured in many countries, it is justified even more for Morocco, given its Mediterranean and arid climate. Indeed, a test pilot conducted in Marrakech has shown that the solar greenhouse drying system allows a large volume reduction of sludge; at least 80% of the initial volume was observed in cold and hot periods after 72 h of the drying process [BELLOULID *et al*. 2017].

CONCLUSIONS

In conclusion, the remarkable development of sanitation in Morocco has inevitably induced the production of sludge from sewage treatment plants in increasing quantities. Consequently, the problem of sludge management becomes persistent and worrying and encourages the implementation of a sustainable strategy so as not to compromise the initial program of liquid sanitation.

Despite the development of a study on the national sludge management strategy and the realization of some recovery pilot projects, the sewage sludge management issue still persists and is becoming more and more worrying.

The constraints hampering the sustainable management of sludge are numerous and complex and have different dimensions: regulatory, institutional organizational, economic-financial and technical dimensions. To overcome these constraints, priority actions should be implemented and can be inspired from the following questions: a) who is the sponsor of the sludge recovery and disposal? b) what is the appropriate sustainable management approach for each case? c) what is the constancy in the quality of the sludge? e) who supports the monitoring and surveillance system? f) who pays for the investments inherent in the implementation of the sludge recovery and disposal projects?

Indeed, the decision-making sphere of the institutional actors concerned will have to be around the same table to define and share responsibilities; the constraints are well identified, and the solutions exist but deserve to be optimized and adapted.

Furthermore, improving the management of sewage sludge in Morocco requires uncovering opportunities, reducing risk profiles and stakeholder engagement. Municipalities, government and academia ideally would be encouraged to participate in the decision-making process. Technical solutions, when coupled with stakeholder participation, can lead to policy implementation with a higher chance of improving the present situation.

In the end, in the Moroccan context, comparing sludge recovery and disposal routes, the green recycling (in agriculture, silviculture and rehabilitation of degraded soils) remains the most environmentally friendly option, a sustainable and economically viable solution.

REFERENCES

ANTONKIEWICZ J., KOŁODZIEJ B., BIELIŃSKA E.J., POPŁAWSKA A. 2019. The possibility of using sewage sludge for energy crop cultivation exemplified by reed canary grass and giant miscanthus. Soil Science Annual. Vol. 70. Iss. 1 p. 21–33. DOI 10.2478/ssa-2019-0003.

ANTONKIEWICZ J., KOŁODZIEJ B., BIELIŃSKA E., WITKOWICZ R., TABOR S. 2018. Using Jerusalem artichoke to extract heavy metals from municipal sewage sludge amended soil. Polish Journal of Environmental Studies. Vol. 27. Iss. 2 p. 513–527. DOI 10.15244/pjoes/75200.

BELLOULID M.O., HAMDI H., MANDI L., OUAZZANI N. 2017. Solar greenhouse drying of wastewater sludges under arid climate. Waste and Biomass Valorization. Vol. 8 p. 193–202. DOI 10.1007/s12649-016-9614-1.

CLAUS-GERHARD B. 2018. EU perspective and German legislation concerning sludge [4th workshop of the IWAMA project: Smart sludge handling in the wastewater treatment sector] [online]. Tartu, Estonia. [Access 19.06.2019]. Available at: www.iwama.eu/sites/iwama/files/2_eu_perspective_and_german_legislation_concerning_sludge_bergs.pdf

COLLIVIGNARELLI M., ABBÀ A., FRATTAROLA A., CARNEVALE-MIINO M., PADOVANI S., KATSOYIANNIS I., TORRETTA V. 2019. Legislation for the reuse of biosolids on agricultural land in Europe: Overview. Sustainability. Vol. 11. No. 21, 6015 p. 1–26. DOI 10.3390/su11216015.

Commission Decision 2001/118/EC of 16 January 2001 amending Decision 2000/532/EC as regards the list of wastes. Official Journal of the European Communities L. 47/1.

Council Directive 91/271/EEC of May 21, 1991 on urban wastewater treatment. Official Journal of the European Communities L 135 p. 40–52.

Council Directive 1999/31/EC of 26 April 1999 on the landfill of waste. Official Journal L 182, 16/07/1999 p. 1–19.

Dahir du 3 chaoual 1332 (25 août 1914) portant réglementation des établissements insalubres, incommodes ou dangereux [Dahir of 25 August 1914 on the regulation of unhealthy, disturbing or dangerous establishments] [online]. Bulletin official. No. 97 du 07/09/1914. [Access 19.06.2019]. Available at: http://www.abhoer.ma/pages_externes//Textes%20juridiques/dahir/Dahir%20du%2025%20ao%C3%BBt%201914%20portant%20r%C3%A9glement%20des%20%C3%A9tablissements%20insalubres%20incommodes%20ou%20dangereux.pdf

Dahir n° 1-03-60 du 10 rabii I 1424 (12 mai 2003) portant promulgation de la loi n° 12-03 relative aux études d'impact sur l'environnement [Dahir No. 1-03-60 of May 12, 2003 on the promulgation of the Law No. 12-03 relative to the studies of impact on the environment] [online]. Bulletin official. No. 5118 of June 19, 2003 p. 507. [Access 19.06.2019]. Available at: http://adala.justice.gov.ma/production/html/Fr/74929.htm

Décret n° 2-07-253 du 14 rejeb 1429 (18 juillet 2008) portant classification des déchets et fixant la liste des déchets dangereux [Decree No. 2-07-253 of July 18, 2008 on the classification of waste and fixing the list of hazardous wastes] [online]. Bulletin official. No. 5654. Annexe I, code 19. [Access 19.06.2019]. Available at: http://maroc-maintenance-environnement.com/wp-content/uploads/2016/02/Decret-2-07-253.pdf

Décret n°2007-13 du 3 janvier 2007, fixant les conditions et les modalités de gestion des boues provenant des ouvrages de traitement des eaux usées en vue de son utilisation dans le domaine agricole [Decree No. 2007-13 of 3 January, 2007 laying down the conditions and methods for sewage sludge management for use in agriculture (Tunisia). Journal Officiel de la République Tunisienne. No. 3. January 9, 2007 p. 92–93. [Access 19.06.2019]. Available at: http://www.legislation.tn/sites/default/files/fraction-journal-officiel/2007/2007F/003/TF2007133.pdf

DGCL 2017. Programme National d'Assainissement Liquide (PNA) [National Program of Liquid Sanitation] [online]. [Access 18.06.2019]. Available at: www.pncl.gov.ma/fr/ grand-chantiers/Pages/PNA.aspx

EDI 2017. Beneficial reuse of biosolids – jurisdictional review. Final report [online]. Victoria. EDI Environmental Dynamics Inc. [Access 16.02.2020]. Available at: www.crd.bc.ca/docs/default-source/irm-reports/consolidationreportnov17/appendixq.pdf?sfvrsn=d99609ca_2

Eurostat 2020. Sewage sludge production and disposal from urban wastewater [online]. Brussels. [Access 27.03.2020]. Available at: https://appsso.eurostat.ec.europa.eu/nui/submitViewTableAction.do

EVAN T. 2012. Biosolids in Europe [online]. Proceeding of the 26th WEF Residuals & Biosolids Conference. Raleigh, USA [Access 16.02.2020]. Available at: http://www.timevansenvironment.com/2012%20Biosolids%20in%20Europe%20-%20Evans%20-%20WEF%20R&B%20Conf.%2002E.pdf

German Environment Agency 2018. Sewage sludge disposal in the Federal Republic of Germany [online]. Dessau-Rosslau. ISSN 2363-832X pp. 101 [Access 16.02.2020]. Available at: https://www.umweltbundesamt.de/sites/default/files/medien/1410/publikationen/190116_uba_fb_klaerschlamm_engl_bf.pdf

GOV.UK 2015. Water and treated water [online]. London. [Access 17.06.2019]. Available at: www.gov.uk/government/publications/water-and-treated-water/water-and-treated-water

Haya Water 2017. An overview of Haya Water [online]. Muscat pp. 23. [Access 16.18.2019]. Available at: https://www.haya.om/Publications/Awareness%20Booklet-A5-ENG.pdf

HAZLEGREAVES S. 2019. What are the alternatives to landfill? [online]. Open Access Government. [Access 16.02.2020]. Available at: https://www.openaccessgovernment.org/what-are-the-alternatives-to-landfill/53719

HORIZON 2020. Dépollution intégrale du lac de Bizerte – Rapport du Diagnostic [Integral depollution of Bizerte Lake – Diagnostic report] [online]. Version Finale MeHSIP-PPIF Mediterranean Hot Spot Investment Programme Project Preparation and Implementation Facility A TA operation funded by the European Union – FEMIP Support Fund. September 2011 pp. 232. [Access 16.18.2019]. Available at: http://www.environnement.gov.tn/images/fichiers/projet_etude/Rapport_diagnostic.pdf

JAFFAR ABDUL KHALIQ S., AHMED M., AL-WARDY M., AL-BUSAIDI A., CHOUDRI B.S. 2017. Wastewater and sludge management and research in Oman: An overview. Journal of the Air and Waste Management Association. Vol. 67. Iss 3. p. 267–278. DOI 10.1080/10962247.2016.1243595.

JAKOBSSON C., GUSTAFSON A., FEHÉR A., SUMELIUS J. 2012. Sustainable agriculture. Uppsala. Coronet Books Inc. ISBN. 978-91-86189-10-5 pp. 505.

KACPRZAK M., NECZAJ E., FIJAŁKOWSKI K., GROBELAK A., GROSSER A., WORWAG M., RORATA A., BRATTEBOB H., ALMÅSC Å., SINGH B.R. 2017. Sewage sludge disposal strategies for sustainable development. Environmental Research Vol. 156 p. 39–46. DOI 10.1016/j.envres.2017. 03.010.

KELESSIDIS A., STASINAKIS A.S. 2012. Comparative study of the methods used for treatment and final disposal of sewage sludge in European countries. Waste Management. Vol. 32 p. 1186–1195.

LEGER C., NBOU M. 2010. Mise en œuvre de la stratégie de gestion des boues issues des stations d'épuration urbaines et industrielles [Implementation of the national strategy of urban and industrial sewage sludge management]. Rabat. MEMEE Département de l'environnement pp. 8.

LENS P., HAMELERS B., HOITINK H., BIDLINGMAIER W. 2004. Resource recovery and reuse in organic solid waste management. IWA Publishing. ISBN 978-1-84339-054-1 pp. 537.

Loi n°28-00 relative à la gestion des déchets et à leur élimination promulguée par le dahir n° 1-06-153 du 30 chaoual 1427 (22 Novembre 2006) [Law No. 28-00 of November 22, 2006 on waste management and disposal promulgated by Dahir n° 1-06-153]. Bulletin official. No. 5480 of December 7, 2006 p. 553–575.

MEMEE 2010. Etude pour l'elaboration de la stratégie nationale de gestion des Boues des Stations d'Epuration des Eaux au Maroc [Study for the elaboration of the national strategy for the management of sludge from water treatment plants in Morocco]. Phase 1 report. Rabat. Département de l'environnement pp. 152.

MEMEE 2015. Situation actuelle de l'assainissement liquide en milieu urbain [Current situation of liquid sanitation in urban areas] [online]. Rabat. [Access 15.03.2019]. Available at: www.environnement.gov.ma/fr/eau?id=207

MEMEE 2018. Liste des stations d'épuration au Maroc [List of wastewater treatment plants in Morocco] [online]. Rabat. [Access 18.06.2019]. Available at: http://www.environnement.gov.ma/images/Mde_PDFs/Fr/pndm08112018/4._Liste_des_STEP_achev_es_compressed.pdf

MORF L. 2012. Phosphorus from sewage sludge – The strategy of the Canton of Zurich and Switzerland [45th Essner conference for waste and water management]. [14–16.03.2012 Essen, Germany].

Muscatdaily.com 2016. Kala: Environment-friendly compost [online]. Muscat. [Access 18.06.2019]. Available at: https://muscatdaily.com/Archive/Oman/Kala-Environment-friendly-compost-4tl0

Oman Daily Observer 2017. Kala compost a hit with farmers [online]. Muscat. [Access 16.06.2019]. Available at: http://www.omanobserver.om/kala-compost-hit-farmers

ONAS 2017. Rapport 2017 des Activités de l'Office National de l'Assainissement (Tunisie) [Activities Report 2017 of the National Sanitation Office (Tunisia)].

ONEE, FAO 2016. Etude d'opportunité de valorisation des boues des STEP – ONEE [Recovery opportunity study of sludge generated from WWTP – ONEE]. Rabat pp. 142

PANTER K., BARBER B. 2017. Extracting energy from sludge in the UK: recent experience. In: WEF Residuals and Biosolids Conference Proceedings. Seattle, Washington. Water Environment Federation p. 550.

PELLEGRINI M., SACCANI C., BIANCHINI A., BONFIGLIOLI L. 2016. Sewage sludge management in Europe: A critical analysis of data quality. International Journal of Environment and Waste Management. Vol. 18. Iss. 3 p. 226–238.

SEU/MECA 2013. Omani environmental regulations international references documents – SEU Guidance Notes. Falaj Al Qabail, Sultanate of Oman. Sohar Environmental Unit. 2nd ed. pp. 320.

SOUDI B. 2015. Gestion des boues générées par les STEP : Dignostic de la situation actuelle et ebauche d'une vision d'amélioration des performances [Management of sludge generated from WWTP: Diagnosis of the current situation and draft of a vision for improving performances]. Rabat. ONEE and FAO pp. 93.

SOUDI B. 2018. Gestion des boues d'épuration au Maroc : Contraintes, opportunités et issues stratégiques [Management of sewage sludge: Constaintes, opportunities and strategic solutions]. [Séminaire national sur les systèmes d'assainissement liquide au Maroc et potentialités de valorisation des sous-produits]. [26.03.2018 Rabat].

SPINOSA L., VESILIND P.A. 2001. Sludge into Biosolids. IWA Publishing. ISBN 978-1-900222-08-2 pp. 424.

SWIM H2020 SM 2018. Assainissement liquide et gestion des boues au Maroc [Liquid Sanitation and sludge management in Morocco] [online]. Athens. [Access 18.06.2019]. Available at: www.swim-h2020.eu/wp-content/uploads/2018/06/SWIM-H2020-SM_Sludge-Management_Morocco.pdf

Water UK 2010. Recycling of biosolids to agriculture land [online]. London. [Access 05.05.2019]. Available at: https://assuredbiosolids.co.uk/wp-content/uploads/2018/05/Recycling-Biosolids-to-Agricultural-Land.pdf

WIECHMANN B., DIENEMANN C., KABBE C., BRANDT S., VOGEL I., ROSKOSCH A. 2013. Sewage sludge management in Germany [online]. Dessau-Rosslau, Germany. German Environmental Agency. [Access 16.02.2020]. Available at: https://www.umweltbundesamt.de/sites/default/files/medien/378/publikationen/sewage_sludge_management_in_germany.pdf