Waste Management 32 (2012) 1186–1195

Contents lists available at SciVerse ScienceDirect

Waste Management

journal homepage: www.elsevier.com/locate/wasman

Review

Comparative study of the methods used for treatment and final disposal of sewage sludge in European countries

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ARTICLE INFO

Article history:
Received 7 October 2011
Accepted 15 January 2012
Available online 14 February 2012

Keywords:
Sewage sludge
Management
European Union
Treatment
Disposal
Reuse
Legislation

ABSTRACT

Municipal wastewater treatment results to the production of large quantities of sewage sludge, which requires proper and environmentally accepted management before final disposal. In European Union, sludge management remains an open and challenging issue for the Member States as the relative European legislation is fragmentary and quite old, while the published data concerning sludge treatment and disposal in different European countries are often incomplete and inhomogeneous. The main objective of the current study was to outline the current situation and discuss future perspectives for sludge treatment and disposal in EU countries.

According to the results, specific sludge production is differentiated significantly between European countries, ranging from 0.1 kg per population equivalent (p.e.) and year (Malta) to 30.8 kg per p.e. and year (Austria). More stringent legislations comparing to European Directive 86/278/EC have been adopted for sludge disposal in soil by several European countries, setting lower limit values for heavy metals as well as limit values for pathogens and organic micropollutants.

A great variety of sludge treatment technologies are used in EU countries, while differences are observed between Member States. Anaerobic and aerobic digestion seems to be the most popular stabilization methods, applying in 24 and 20 countries, respectively. Mechanical sludge dewatering is preferred comparing to the use of drying beds, while thermal drying is mainly applied in EU-15 countries (old Member States) and especially in Germany, Italy, France and UK.

Regarding sludge final disposal, sludge reuse (including direct agricultural application and composting) seems to be the predominant choice for sludge management in EU-15 (53% of produced sludge), following by incineration (21% of produced sludge). On the other hand, the most common disposal method in EU-12 countries (new Member States that joined EU after 2004) is still landfilling. Due to the obligations set by Directive 91/271/EC, a temporary increase of sludge amounts that are disposed in landfills is expected during the following years in EU-12 countries. Beside the above, sludge reuse in land and sludge incineration seem to be the main practices further adopted in EU-27 (all Member States) up to 2020. The reinforcement of these disposal practices will probably result to adoption of advanced sludge treatment technologies in order to achieve higher pathogens removal, odors control and removal of toxic compounds and ensure human health and environmental protection.

1. Introduction

During the last 20 years, the implementation of Urban Waste Water Treatment (UWWT) Directive 91/271/EC (CEC, 1991) forced EU-15 countries (old Member States) to improve their wastewater collecting and treatment systems. As a result, an almost 50% increase of annual sewage sludge production in EU-15 was noticed, from 6.5 million tons dry solids (DS) in 1992 to 9.8 million tons DS in 2005 (Hall, 1995; EC, 1999, 2004, 2006; EEA, 2002; BIOPROS, 2006; http://epp.eurostat.ec.europa.eu). On the other hand, the annual sewage sludge production in EU-12 (new Member States) was estimated to be 1.1 million tons DS in 2005 (http://epp.eurostat.ec.europa.eu), resulting to a total amount of 10.9 million tons DS for EU-27 (all Member States) in 2005. It is obvious that the implementation of UWWT Directive (CEC, 1991) by EU-12 countries is going to cause a significant increase of annual sewage sludge production in EU during the following years, exceeding 13 million tons DS up to 2020 (Milieu Ltd., WRc and RPA, 2010; Leonard, 2011).

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doi:10.1016/j.wasman.2012.01.012

So far, there is not a clear view concerning sewage sludge handling (treatment and disposal practises) as well as relative legislation in EU area. Some relevant reports have been published by Eurostat, European Commission (EC) and European Environmental Agency (EEA); however, most of them refer mainly to agricultural utilization of sludge; whereas they are usually incomplete, inhomogeneous and contain sometimes contradictory data (Jacobsen et al., 1997; EC, 1999, 2004, 2006, 2009; EEA, 2002; EL and IEEP, 2009). The lack of continuity among these reports and the relevant lack of data for new Member States complicate further the study of this topic. On the other hand, limited scientific papers have been published, comparing sewage sludge management and legislation in different European countries. Most of them are quite old (Hall, 1995; Davis and Hall, 1997; Leschber et al., 2002) or report data for specific EU countries (Przewrocki et al., 2004; Jensen and Jepsen, 2005). Contrary to sludge management, several papers are available in literature comparing other wastewater management options in EU countries; such as wastewater treatment and reuse (Angelakis et al., 1999; Angelakis and Bontoux, 2001; Bixio et al., 2006).

The main objective of the current study was to review published reports on sludge management in EU countries and to unify existed data in order to outline the current situation and discuss future perspectives for sludge treatment and disposal in EU countries. Comparison of sludge management issues between old and new EU Member States was performed and the specific conditions for each country were discussed based on most recent available data. For this purpose, EC's reports concerning the implementation of UWWT Directive (CEC, 1991) and Sewage Sludge Directive 86/278/EC (CEC, 1986) for the period 1992–2006, data originated from Eurostat, EEA and other organizations as well as references from individual countries were used.

2. Sewage sludge production in EU-27

Sewage sludge production seems to be differentiated significantly between different countries in European area (Table 1). Between EU-15 countries, the highest sludge production was observed in Germany, UK, Spain, France and Italy (Table 1). These countries contribute to almost 73% of total sludge produced in EU-15. Regarding EU-12 countries, Poland was the greatest sludge producer, producing almost 42% of total sludge amounts, while Malta was the smaller (Table 1). It should be mentioned that Poland, Hungary and Czech Republic contribute to more than 70% of produced sludge in this group of countries.

Comparison of specific sludge production (expressed as kg per p.e. and year) shows that the highest specific sludge production for all EU-27 countries is observed in Austria, followed by UK, Finland and Luxembourg (Table 1). Significant differences are observed between different countries as well as between old and new Member States, resulting to mean specific sewage sludge production equal to 21.9 and 11.5 kg per p.e. and year for EU-15 and EU-12, respectively. These differences are due to variations in percentages of population that are served by centralized wastewater treatment systems (WWTSs) as well as to variations in wastewater treatment applied in each country and contribution of the industrial sector. According to Wieland (2003), more than 90% of population in Germany, Netherlands and UK is connected to urban wastewater treatment, whereas lower percentages are observed in Mediterranean and Eastern Europe countries. Regarding the type of treatment applied, some countries such as Finland, Germany, Denmark, Sweden and Netherlands apply tertiary treatment in municipal wastewater at percentages higher than 80%, while secondary treatment is predominant in Southern and EU-12 countries (Wieland, 2003). Moreover, it is known that the use of extended biological processes (e.g. extended aeration systems, constructed wetlands) produce smaller amounts of sludge comparing to WWTSs that apply conventional activated sludge process or use physico-chemical methods for phosphorus removal (Tchobanoglous et al., 2002). Calculation of specific sewage sludge production per population equivalent served by WWTS (p.e.s.) show that the highest specific sludge production for EU-27 countries is observed in Cyprus, followed by Finland, Hungary, and Austria (Table 1). In this case, mean specific sewage sludge production is equal to 25.4 and 21.1 kg per p.e.s. and year for EU-15 and EU-12, respectively.

3. Sewage sludge legislation in EU-27

According to UWWT Directive (CEC, 1991), the collection and treatment of municipal wastewater is compulsory for agglomerations with p.e. of 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 UWWT Directive was 2005 for the older EU-15 Member States and 2015 or 2018 for the countries that joined EU after 2004 (EC, 2009).

On the other hand, Decision 2001/118/EC (CEC, 2001) enlist sludge in non hazardous wastes (Chapters 19 and 20), whereas according to European policy the following waste hierarchy shall apply as a priority order in waste management: (a) Prevention, (b) Preparing for re-use, (c) Recycling, (d) Other recovery, e.g. energy recovery, (e) Disposal. Based on these principles, the Landfill Directive 99/31/EC (CEU, 1999) prohibited landfilling of both liquid and untreated wastes and set restrictions as well as quantitative targets for bio-degradable municipal solid wastes (such as sewage sludge) that are disposed in landfills. According to these, a reduction of 50% and 65% of produced solid waste by years 2013 and 2020 should be achieved, respectively. Apart from the above, national legislations 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 (Table 2).

Additional to the above, the main legislative text that refers to sludge management is Sewage Sludge Directive 86/278/EEC (CEC, 1986) which describes beneficial sludge (biosolids) 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 (Table 2). Specifically, 16 out of 27 EU countries (63%) have set more stringent national requirements for heavy metals concentrations in sludge comparing 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 Netherlands) have set the lowest limit values. On the other hand, except of France, Malta and Slovenia, Mediterranean countries have adopted the limit values that are proposed by EU Directive (Table 2).

Apart from heavy metals included in EU Directive 86/278, several countries have set limit values for chromium as well as for other categories of pollutants commonly detected in sludge such as pathogens and organic micropollutants. Limit values for total chromium in sludge have been set by 19 out of 27 countries (70%), while different legislation on this matter is observed in different Belgium areas (Table 2). The limit values of total Cr range from 40 mg kg^{-1} DS (Slovenia) to 1750 mg kg^{-1} DS (Luxembourg).

Table 1
Amounts of sewage sludge and specific sewage sludge production for total population and population served by WWTS in EU-27 countries. The year that data is available for sewage sludge production is reported in brackets (http://epp.eurostat.ec.europa.eu).

Country	Sewage sludge production (10^3 ton DS/year)	Specific sewage sludge production (kg/p.e./year)	Specific sewage sludge production (kg/p.e.s.[a]/year)
Germany (2005)	2170	26.3	27.7
United Kingdom (2005)	1771	29.5	32.0
Spain (2005)	1121	26.0	28.6
France (2004)	1059	17.0	21.3
Italy (2005)	1053	18.1	19.2
Netherlands (2005)	348	22.0	22.2
Austria (2006)	254	30.8	33.5
Sweden (2005)	210	23.3	27.1
Portugal (2007)	189	18.0	26.1
Finland (2005)	148	28.2	34.8
Denmark (2007)	140	26.0	29.2
Greece (2005)	115	10.5	12.4
Belgium (2004)	103	10.8	20.4
Ireland (2005)	60	14.6	17.3
Luxemburg (2003)	14	27.8	29.2
EU-15	*9806*	*21.9*	*25.4*
Poland (2005)	486	12.7	21.2
Hungary (2004)	184	18.2	33.7
Czech Republic (2005)	172	16.8	23.0
Romania (2005)	68	3.1	11.6
Lithuania (2005)	66	19.1	27.8
Slovakia (2005)	56	10.5	19.1
Bulgaria (2005)	42	5.4	13.1
Estonia (2005)	29	22.1	29.9
Latvia (2005)	27	12.5	20.0
Slovenia (2005)	14	6.8	18.4
Cyprus (2005)	7	11.1	36.8
Malta (2005)	0.1	0.1	0.2
EU-12	*1151*	*11.5*	*21.1*
EU-27	*10,957*	*17.7*	*24.3*

[a] p.e.s.: population equivalent served by WWTS.

So far, except of Hungary that has set a limit value of 1 mg kg^{-1} DS for Cr(VI), no limit values have been set for this chromium species by other European countries, despite the fact that it is considered much more toxic than total chromium (Stasinakis and Thomaidis, 2010). Similarly to EPA regulations (U.S. EPA, 1992), 11 out of 27 countries (41%) have set limit values for pathogens (Table 2). In most cases, these limit values refer to the existence of salmonella, enterovirus and helminths eggs. Regarding organic micropollutants, 9 out of 27 countries (33%) have set limit values for several synthetic organic compounds. Among them, 7 belong to old EU countries and only 2 (Czech Republic and Slovenia) in new EU countries (Table 2). The proposed chemical compounds and the maximum acceptable values differentiate between countries. In general, halogenated organic compounds, linear alkyl benzene sulphonates (LAS), phthalates, nonylphenols, polycyclic aromatic hydrocarbons, polychlorinated biphenyls (PCBs) and polychlorinated dibenzodioxins/dibenzofuranes have been included in these national legislations and their limit values range between 0.2 mg kg^{-1} DS (PCBs) to 1300 mg kg^{-1} DS (LAS).

Most EU countries have prohibited the disposal of untreated sludge in soil (Table 2). In some cases, specific obligations for treatment have been set such as biological or chemical stabilization before reuse, while there are 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, silviculture, mines and green areas has been prohibited in several countries (Table 2).

4. Sewage sludge treatment methods in EU-27

A great variety of sludge treatment technologies is used in EU-27, which are related with the final disposal practices and the size of WWTS. According to Table 3, significant differences can be observed between EU Member States as well between different regions of the same country (e.g. Belgium).

Regarding sludge stabilization, anaerobic and aerobic digestion seem to be the most common used methods in EU-27, applying in 24 out of 27 countries (89%) and 20 out of 27 countries (74%), respectively. Anaerobic digestion is most commonly used in Spain, UK, Italy, Finland and Slovakia, whereas aerobic digestion is the prevailing technology in Czech Republic and Poland (Table 3). Having in mind that aerobic digestion is usually applied in cases of small WWTSs, even in the aforementioned countries the greatest part of produced sludge is treated anaerobically. For instance, in Czech Republic anaerobic stabilization is applied to approximately 97% of sludge (EC, 2006). The p.e. criterion for using anaerobic digestion instead of aerobic varies between different countries ranging between 5000 p.e. in Czech Republic and 50,000 p.e. in cases of Italy and Austria. Chemical stabilization, conditioning with lime or other chemicals are generally of minor importance, although they are used mainly in some EU-15 countries (Table 3). On the other hand, composting is used in 25 out of 27 countries (93%). However, in most Member State's reports, it is reported as sludge disposal method, causing confusion on extrapolation of the results. In fact, most composting applications constitute advanced stabilization treatment in order to achieve sludge hygienization for land use.

It should be mentioned that some countries such as Germany apply combinations of technologies, e.g. anaerobic stabilization followed by lime treatment. An innovative stabilization technique that is also applied in more than 20 German WWTSs since 1990 is a combination of mesophilic and thermophilic anaerobic digestion in different stages with multiple reactors, called Temperature-Phased Anaerobic Digestion (TPAD).

Table 2
Comparative presentation of current national requirements and 86/278/EEC provisions for sludge disposal on soil (EC, 2001; Le Blanc et al., 2008; Eco Logic, 2009; Milieu Ltd., WRc and RPA, 2010).

Country	Heavy metals in sludge	Heavy metals in soil	Maximum annual loads of heavy metals	Limit values for chromium (not included in 86/278/EEC)			Limit values for pathogens (not included in 86/278/EEC)	Limit values for organics (not included in 86/278/EEC)	Obligations for treatment	Specific requirements for other routes (forest, silviculture, etc.)	Specific requirements for landfill
				Sludge	Soil	Annual load					
EU-15											
Austria	↓	=	↓↓	*	*	*	•	•	Biological stabilization	Prohibition of use in forest	TOC < 5%
Belgium (Flanders)	↓	↓	↓↓	**	**	**		•	P	Prohibition of use in forest	
Belgium (Wallonia)		=						•	=		
Denmark	↓↓	↓↓	↓↓	**	**	**	•	•	Stabilization, composting or pasteurization	Only pasteurized sludge in green areas	
Finland	↓↓	↓	↓↓	**	*	**	•		Digestion or lime stabilization		
France	↓	=	↓↓	*	*	*	•	•	A	Allowed in forest provided risks have been minimized. Prohibition of use in mines or quarries	DS > 30%
Germany	↓	=		*	*			•	P	Prohibition of use in forest, silviculture and green areas	Organic matter < 5%
Greece	=	=	=	*		*			P		
Ireland	=	=	↓			*			=		
Italy	=	=	↓			*	•		P		Prohibition of waste not submitted to recycling or recovery
Luxembourg	=	=	=	*	*	*	•		=	Additional authorization requirements for forests	
Netherlands	↓↓	↓		**	**				P	Prohibition of use in forest (partly) and green areas	Organic matter < 5%
Portugal	=	↑	=	*	*		•		P		
Spain	=	↑	=	*	*	*			P		
Sweden	↓↓	↓↓	↓↓	*	*	**		•	A		No organic waste is accepted in landfill
UK	-	↑	↓		*				=		
EU-12											
Bulgaria	=	=	=		*		•		P		
Cyprus	=	=	=						P		
Czech Republic	↓			**			•	•	P		
Estonia	=	=	=	*	*	*			A	Land reclamation and green areas follow the same legislation as for agriculture	
Hungary	↓	↓	↓	*		*	•		P		>25% DS, leaching tests
Latvia	↓	↓	↓↓	*	**	**			P		
Lithuania	=	↓↓	=		**	*			P		
Malta	↓	↓		*	**						
Poland	↓	=			*		•		Chemical treatment, heat treatment or other treatments	Limit values for sludge use in land reclamation and green areas	
Romania	↓	=	=		*	*			P		
Slovakia	↓	↓	↓↓	*	**	*			P		
Slovenia	↓↓	=	↓↓	**	*	*		•	P		TOC < 18%

•, limit values have been set for this country.
=, national requirements similar to EU provisions.
↓, national requirements more stringent than EU provisions (at least for some elements).
↓↓, national requirements much more stringent than EU provisions.
↑, national limit values less stringent than EU provisions (allowed for pH > 7).
*, high/medium limit values for chromium.
**, low limit values for chromium.
P, prohibition of use of untreated sludge.
A, allow the use of untreated sludge under certain authorized conditions.

Table 3
Sludge treatment methods applied in EU Member States (EC, 2001, 2006; Spinosa, 2011; EL and IEEP, 2009; Milieu Ltd., WRc and RPA, 2010).

Country	Stabilization				Conditioning				Dewatering				Others						Type of stabilization (where available)
	Aerobic	Anaerobic	Lime	Composting	Lime	Other inorganics (NH_3, iron, salts)	Polymers	Thermal	Drying beds	Filter press	Centrifuges	Belt filter press	Thermal drying	Solar drying	Pasteurization	Long term storage	Cold fermentation	Bag filling	
EU-15																			
Austria	X	X	x	X		x	X			X	X	X	X		X				MAn, TAn
Belgium (Flanders)	X	X	X	x									XX				X		MAn
Belgium (Wallonia)	X	X		x	X		X			X	X	X	X						
Denmark	X	X	X	X									X		X				MAn, TAn
Finland	X	XX	x	XX															MAn, TAn
France	X	X	X	X	X					X	X		X	X					
Germany		X	X	x				X					XX						
Greece	X	X	X	x			X		X		X	X	X	X					MAn
Ireland	X	X	X	x							X	X	X			X			TA
Italy	X	XX	X	X	X	X		X	X	X	X	X	x		x				
Luxembourg		X		X	X	X	X									X			
Netherlands	X	X		X									X						
Portugal	X	X							X	X	X	X	X						
Spain	X	XX	X	x									X			X			
Sweden	X	X	X	X		X		X	X		XX	X	X						TAn
UK	X	XX	X	X							X	X	X			X			MAn, TA
EU-12																			
Bulgaria	X	X	X	x						X						X			MAn
Cyprus	X	X		x						X	X					X			MAn
Czech Republic	X	XX		XX															MAn, TAn
Estonia		X		XX															MAn
Hungary		X		XX							X	X				X			
Latvia		X		x													X		MAn
Lithuania	X		X	X												XX			
Malta																			
Poland	XX	X	X	x					X	X	X	XX				X		X	
Romania				X					X										
Slovakia	X	XX	x	XX															MAn, SeA, SiA
Slovenia	X	x		x						X	x	X	X						

x, rare method.
X, common use.
XX, most common use.
MAn, mesophilic anaerobic digestion.
TAn, thermophilic anaerobic digestion.
TA, thermophilic aerobic digestion.
SeA, separated aerobic digestion.
SiA, simultaneous aerobic digestion.

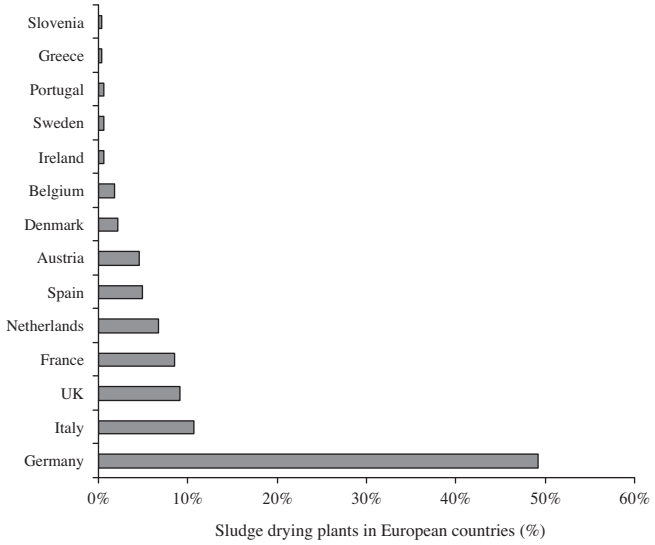

Fig. 1. Distribution of sludge drying plants in European countries (EC, 1999; Le Blanc et al., 2008; HMEPPPW, 2009; Drace medioambiente, 2010; http://www.waterworld.com; http://andritz.com; http://www.environ.ie/en/; http://www.web4water.com; http://www.waterworld.com; http://www.hse.gov.uk).

As far as concerning the new EU countries, Czech Republic is the region's leader in sludge management innovation (Le Blanc et al., 2008). This can be illustrated by the full-scale use of mechanical sludge disintegration and the use of sludge lysate being produced during the disintegration or by rich experience on thermophilic anaerobic digestion (Zabranska et al., 2009). Such innovative techniques of disintegration by mechanical (ultrasound, mills, homogenizers), thermal, chemical (acids, lyes) and biological (enzymes) means have also been studied and applied mainly in Germany and less in Sweden and Italy with encouraging results (WPCF, 1989; Kunz et al., 1996; Lee and Welander, 1996; Sakai et al., 1997; Krogmann et al., 1997; Muller, 2000; Le Blanc et al., 2008).

On the other hand, sludge dewatering seems to be an important step in sludge management of most EU-27 countries. According to Table 3, the majority of European WWTSs use mechanical dewatering instead of drying beds that are preferred mainly in small WWTSs and are reported in 6 out of 27 European countries. From financial point of view, the prevailing sludge dewatering technologies in descending order are centrifuges (41%), belt filter presses (28%) and filter presses (23%) (www.frost.com).

Regarding other sludge treatment methods applied in European countries, thermal drying has prevailing position in sludge management of EU-15 (Table 3). It should be mentioned that 110 thermal drying plants were operated in EU in 1995 (Hall, 1995), the drying lines were increased to about 370 in 1999 (EC, 1999), while today they exceed 450. Most of these plants constitute the first stage of incineration units. Fig. 1 represents distribution of sludge drying plants in European countries. Except of Luxembourg and Finland, all EU-15 countries apply this technology (Drace medioambiente, 2010; Milieu Ltd., WRc and RPA, 2010). As Fig. 1 reveals, the big majority of thermal drying plants (almost half of them) are operated in Germany, following by Italy, UK and France. Rotary Drum Dryers (RDD) is the most commonly used system, following by other types as Fluidized Bed Dryers (FBD) or Belt Dryers (BD) (http://www.web4water.com/library/print.asp?id=3539; Arlabosse et al., 2012). An innovative method called Direct Microwave Drying has also been used in Ireland (Turovskiy and Mathai, 2006). On the other hand, excepting Slovenia, there are no thermal drying units in the new EU-12 countries (Fig. 1).

Long term storage is also applied in several old or new Member States (9 out of 27) as it is an easy and cheap method for sludge management but it requires proper climates and great areas. Other methods such as cold fermentation, solar drying or pasteurization are scarcely referred in a limited number of countries (Table 3).

5. Sewage sludge disposal in EU-27

The change of sewage sludge disposal methods in EU-15 after implementation of 91/271 Directive (CEC, 1991) can be seen in Fig. 2. It should be mentioned that the most recent available data for all European countries are these of 2005. According to the results, landfilling presents a significant and continuing decrease between 1992 and 2005, from 33% to 15%. On the other hand, sludge incineration has been almost doubled (from 11% to 21%), following the estimate-target (EC, 1999). Biosolids reuse, which mainly includes agricultural utilization and composting, has been slightly increased, while an important part of total sludge production (9% in 2005) has been managed using several practices. This part of sludge is reported in several reports as "others" and include methods such as pyrolysis, temporary storage (e.g. Greece, Italy), long storage (e.g. Poland, Estonia, Lithuania), reuse in green areas and forestry (e.g. Ireland, Latvia, Slovakia), landfill cover (e.g. Sweden, Flanders), exportation of sludge amounts to other countries (e.g. granulated sludge from Netherlands to Germany for incineration, sludge for composting or incineration from Luxembourg to Germany) as well as possible differences between total sludge production and disposal amounts. Besides the banning of sludge dumping to the sea after 1998, it is possible that high values of "others" observed in 2000 could also be due to the continued apply of this practice in some European countries (EC, 2004).

Sludge disposal methods for year 2005 in EU-15 and EU-12 are presented in Fig. 3a and b, respectively. As it can be seen, the philosophy of sludge management is quite different between old and new Member States. The prevailing technology in EU-15 is recycling in agriculture (44%). In contrary, the status in new countries is quite unclear, as for 35% of sludge no specific disposal manner is declared. This uncertainty mainly originates from Poland which, as it was mentioned in Section 2, is the greatest sludge producer in EU-12 countries. Almost half of produced sludge in Poland (48%) has no specific outlet, while according to data reported in BIOPROS project (2006), it seems that this percentage include stockpiling and lagooning. Taking into account this notice, landfilling (28%)

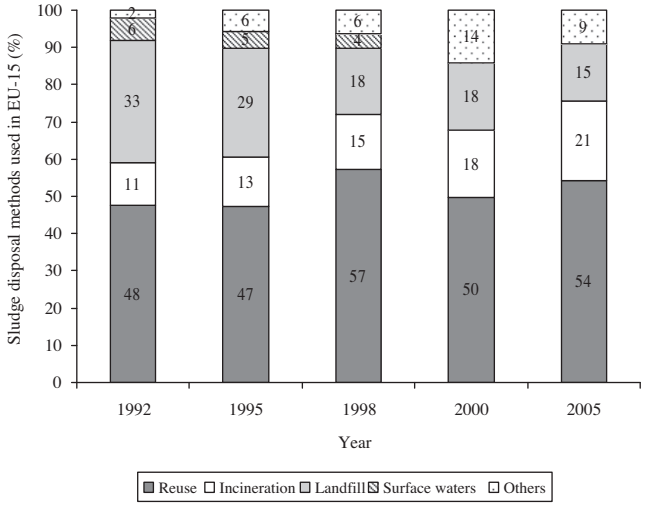

Fig. 2. Sludge disposal methods applied in EU-15 between 1992 and 2005 (year 1992 does not include Italy, Sweden, while year 1998 does not take into account Italy due to lack of data) (http://epp.eurostat.ec.europa.eu; Hall, 1995; EC, 1999, 2004, 2006; EEA, 2002; BIOPROS, 2006; HMEPPPW, 2007; Milieu Ltd., WRc and RPA, 2010).

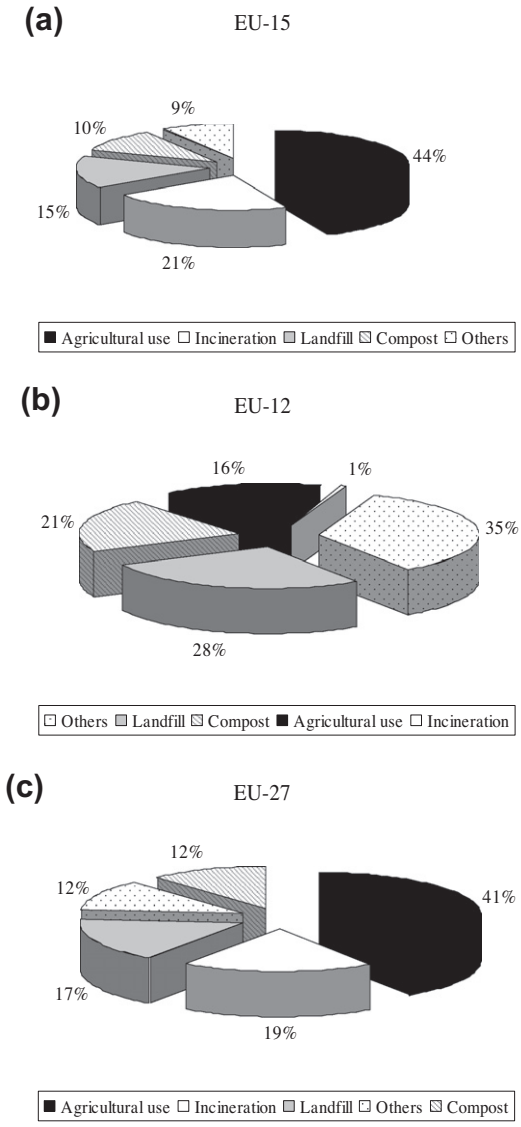

Fig. 3. Sludge disposal methods in EU-15 (a), EU-12 (b) and EU-27 (c) for year 2005 (http://epp.eurostat.ec.europa.eu; EC, 1999, 2004, 2006; EEA, 2002; BIOPROS, 2006; HMEPPPW, 2007).

is considered the most common final disposal method of sludge in EU-12 countries (Fig. 3b), having twofold penetration compared to EU-15 (Fig. 3a).

On the other hand, the second most preferable disposal practice in old Member States is incineration (21%), while this technology is scarcely applied in EU-12 (Fig. 3b). Regarding composting, this method is applied more often in EU-12, comparing to EU-15 countries (Fig. 3a and b). At the moment, the distribution of applied sludge disposal methods in whole European Union (EU-27) is very close to that of EU-15 (Fig. 3a and c), as the old Member States produce almost 90% of the total amount of sludge (Table 1).

Based on the most recent data available from Eurostat (http://epp.eurostat.ec.europa.eu) for sludge disposal methods in different European countries, a descending sorting of EU-27 Member States in "green" line can be created, having in mind that total sludge reuse is the first choice in hierarchy of European Environmental Policy, while incineration is the second (Decision 2001/118/EC, Directive 2008/98/EC). It should be mentioned that in many cases, there is unevenness among countries' data concerning the use of terms. For instance, composting is often included in agricultural utilization and vice versa. According to Fig. 4, the "greener" Member State is Finland with nearly 100% biosolids reuse, almost exclusively after composting (97%). Luxembourg, Cyprus and Portugal follow, reusing more than 87% of produced sludge either directly in agriculture or after composting. The last positions concerning environmentally accepted sludge management practices are occupied by Malta (100% landfill), Greece (46% 'exported' incineration and 39% landfill) and Slovenia (63% 'exported' incineration and 18% landfill).

More than 50% of EU-27 countries apply direct sludge agricultural use to a percentage higher than 50%, while older EU countries seem to be "greener" than new ones (Fig. 4). Specifically, agricultural reuse has been adopted by 21 Member States, while 7 of them (only Hungary from EU-12) apply this practice at percentages higher than 50%. Eighteen countries apply composting before land use, but only 3 of them have percentages higher than 50% (Finland, 97%; Estonia, 78% and Slovakia, 67%). On the other hand, incineration is applied in 17 countries including Greece and Slovenia that export sludge for incineration. Netherlands presents the greater preference in all types of incineration (68%), followed by Belgium (53%) and Germany (51%). Sludge management practices vary significantly among regions of the same country. Typical examples are Belgium and UK. In Flemish region of Belgium, incineration is applied in 88% of produced sludge, while in Brussels region 42% of sludge is landfilled and in Wallonia 35% of sludge is used in agriculture. Similarly in UK, Scotland and Northern Ireland prefer incineration (65% and 36%, respectively), while England and Wales traditionally prefer recycling to agricultural land.

Wide variations on the type of incineration applied are noticed among different Member States (EC, 2004). Germany, UK and Denmark have been at the forefront of mono-incineration, having 23, 11 and 5 dedicated sludge incinerators, respectively, while Netherlands, France, Belgium, and Czech Republic seem to chose co-incineration. Innovative technologies such as pyrolysis, gasification and wet oxidation are under research in some cases, but still beyond a wide commercial apply in European area. The most important wet oxidation facility is the deep shaft technology in Netherlands. A similar method has also been used since 2008 in the new Northern WWTSs (Brussels region, Belgium).

6. Current trends and future perspectives

An estimation of current trends in sludge disposal practices applied in EU-27 is shown in Table 4. For this reason, recent data (up to 2009) originated from Eurostat (http://epp.eurostat.ec.europa.eu) for European countries have been compared with data of year 2000 (BIOPROS, 2006; EC, 2006). It should be mentioned that some of these data, especially those of EU-12, have low reliability. Furthermore, in some countries the amounts of sludge that are reported as "others" are significant (e.g. Lithuania), affecting the calculation of sludge percentages that are disposed otherwise.

According to the results presented in Table 4, a significant abandonment of sludge landfilling is noticed in most European countries, whereas only three countries report a slight increase of landfill use (Italy, Denmark, Estonia). Incineration is enforced in most EU-15 countries. Greece and Slovenia present the greatest increasing trends (Table 4), however as mentioned in Section 5 these countries export sludge for incineration. Between other EU-15 countries, Germany (28%) and Netherlands (16%) appear the greatest development of this technology, while Denmark (−22%) and Belgium (−12%) present a decreasing trend. From new Member States, only Cyprus seems to invest in incineration facilities. Regarding agricultural reuse, an increasing trend is observed in 7 out of 15 old countries and 6 out of 12 new countries. The most

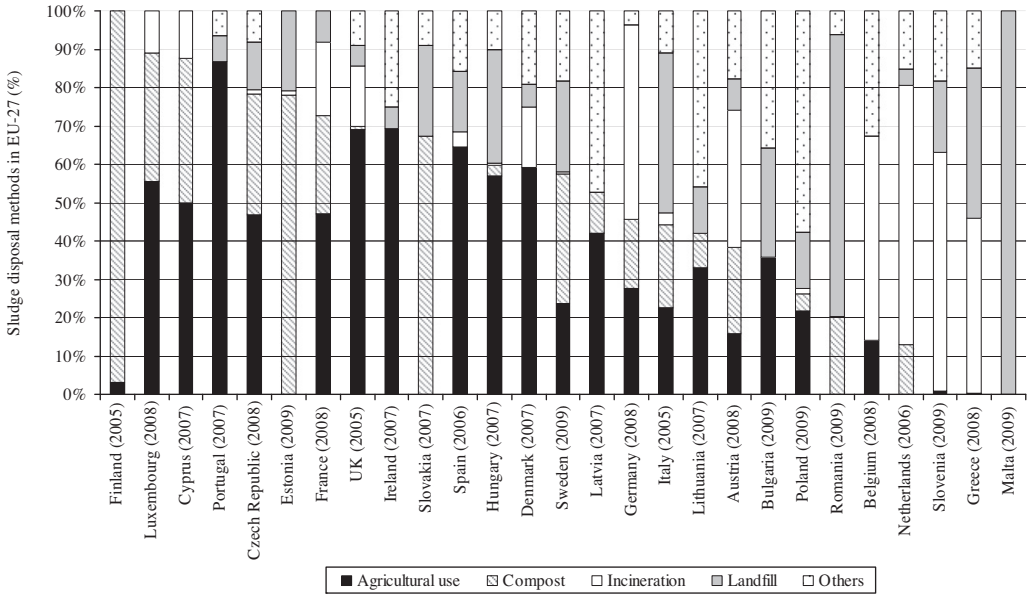

Fig. 4. Descending sorting of EU-27 Member States in "green" line (in parenthesis, the year where available data exist) (http://epp.eurostat.ec.europa.eu; Milieu Ltd., WRc and RPA, 2010; HMEECC, 2010).

Table 4
Trends on sludge disposal methods applied in EU-27 countries between 2000 and 2009 (BIOPROS, 2006; EC, 2006; http://epp.eurostat.ec.europa.eu).

Country	Agricultural use (%)	Compost (%)	Incineration (%)	Landfill (%)
EU-15				
Austria	4	−5	−12	−5
Belgium	3	0	−1	−19
Denmark	−1	0	−22	4
Finland	−9	17	0	−6
France	−3	20	2	−16
Germany	−4	−8	28	−6
Greece	−2	−1	46	−56
Ireland	28	0	0	−44
Italy	−4	−10	−2	12
Luxembourg	−15	22	11	−18
Netherlands	0	2	16	−14
Portugal	71	0	0	−77
Spain	11	0	−4	−2
Sweden	8	2	0	−12
UK	13	1	0	−3
EU-12				
Bulgaria	36	0	0	−72
Cyprus	50	38	13	−100
Czech Republic	−28	31	1	−9
Estonia	−10	74	1	4
Hungary	31	−20	1	−16
Latvia	13	4	0	−38
Lithuania	23	9	0	−78
Malta	0	0	0	0
Poland	8	−3	0	−28
Romania	0	20	0	−27
Slovakia	−63	67	0	−1
Slovenia	−3	−11	63	−67

significant increase is observed in Portugal, Cyprus and Bulgaria (Table 4). On the other hand, a significant decreasing trend in agricultural reuse is observed in countries such as Slovakia and Czech Republic. In these cases, composting seems to replace direct agricultural reuse (Table 4). It should be mentioned that the observed trends depend on local political, social and legal conditions. Relevant examples can be observed in Germany, Sweden, Czech Republic and Flanders. For instance, the adaptation of strict legal restrictions on Probable Toxic Elements detected in sludge by Flanders in 1998, resulted to a significant decrease of agricultural reuse from 22% (1998) to 2% (2002).

According to the latest relative EU projects (EL and IEEP, 2009; Milieu Ltd., WRc and RPA, 2010), all Member States of EU-27 will probably have completed their obligations regarding Directive 91/271 by 2020. Based on this scenario, sewage sludge production will be increased by 20% in EU-15 and by 100% in EU-12. Having in mind the urgent situation that new countries will face out, a temporary increase of sludge amounts that will be landfilled could be expected in EU-12 during the following years. However, a predominance of agricultural reuse could be expected up to 2020 due to the agricultural lands found in these countries, the global financial recession and the low cost of this technology. Regarding EU-15 countries, agricultural recycling (direct or after composting) and incineration seem to be the two main practices that will be further adopted.

Incineration procedures have been undergone significant improvements during the last years concerning technology level, cost reduction and environmental protection. However several topics such as the cost of treatment of flue gases and ashes, the emissions of dioxins and furans, the release of heavy metals and the handling of solid residues are still of significant important for thermal processes (Fytili and Zabaniotou, 2008). Old Member States will continue to lead on these technologies and probably by 2020 thermal treatment with energy recovery could have a share of 37%, over-doubled compared to EU-12. It is possible that co-incineration in coal-fires, use of cement kilns plants or Municipal Solid Waste (MSW) incinerators are going to be preferred, except from cases that phosphorus recovery is pursued. Several technologies for phosphorus recovery from sewage sludge have been performed in large-scale projects worldwide (Dichtl et al., 2007). However the aforementioned technology as well as other innovative technologies such as pyrolysis seem to continue being of minor importance for the following years for most European countries. The further adoption of incinerations technologies will also result to adoption of drying technologies as this is necessary for transfer cost reduction and increase of sludge heating value. Solar drying could be an economic alternative to conventional drying systems, especially in areas with proper climatic conditions (Dichtl et al., 2007).

Regarding agricultural reuse, it should be mentioned that this will be combined with adoption of advanced sludge treatment technologies, aiming to achieve higher pathogens removal, odors control and removal of toxic compounds. Such technologies could be thermal drying, composting, thermophilic anaerobic digestion, autothermal thermophilic aerobic digestion and lime treatment. Enhanced production and utilization of biogas could also be expected, in compliance with Renewable Energy Directive (EP and CEU, 2009), using multi-staged anaerobic digestion, co-digestion with MSW or thermophilic anaerobic digestion.

Based on current trends, local conditions and future sludge management projects of Member States, we can forecast their future trends (landfill diminishing is a common fact for all countries) and thus distinguish them in the following groups:

- *Group 1: Increasing agriculture use only:* France, Malta.
- *Group 2: Status quo:* Germany, Estonia, Netherlands, Cyprus.
- *Group 3: Increasing incineration only:* Austria Portugal Slovakia Hungary, Belgium (mainly) and Latvia, Denmark, Ireland, Luxembourg (less).
- *Group 4: Increasing (mainly) agriculture and incineration:* Sweden (major shift to composting and co-incineration), Czech Republic (composting), Lithuania, Poland (composting), Romania, Slovenia, UK.
- *Group 5: Increasing agriculture and (mainly) incineration:* Spain, Italy (composting), Bulgaria, Finland, Greece.

The above classification indicates a clear shift in sewage sludge management in EU countries and could be useful for evaluating the future agricultural and energy policy of each Member State.

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