Sewage sludge management in Europe: a critical analysis of data quality

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Abstract: The paper analyses the way numerical data on sewage sludge quantities are recorded, processed and then reported at EU level. The analysed data are the same used by policy makers as official sources. The paper shows the difficulties found during the comparison of EU member states management systems, starting from lack of homogeneity and the fragmentation of the data. Reliable data about sewage sludge production and disposal are indispensable to make a critical analysis and also to realise adjustments and changes to the existing management models as well as in the implementation of European policies, such as the Sewage Sludge Directive or the Urban Wastewater Treatment Directive. Moreover, starting from a critical analysis of EU data, the paper shows how sewage sludge management is dealt by EU countries. Finally, the paper suggests to policy makers some implementation for the data management system in order to reach a higher data reliability.

Keywords: data analysis; data quality; sewage sludge management; European legislative framework.

Reference to this paper should be made as follows: Bianchini, A., Bonfiglioli, L., Pellegrini, M. and Saccani, C. (2016) 'Sewage sludge management in Europe: a critical analysis of data quality', *Int. J. Environment and Waste Management*, Vol. 18, No. 3, pp.226–238.

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1 Introduction

The management of sewage sludge, which is the sludge originating from the process of treatment of wastewater, is a problem of great concern in Europe. In fact, about 10 million tons dry matter (DM) of sewage sludge is estimated as produced in Europe every year (Milieu Ltd et al., 2008): 8.7 million tons DM in the old member states (EU-15) and an additional 1.2 million tons DM for the 12 new member states (EU-12). This value refers to the period 2003–2006: the authors refer to this study, although not recent, because it represents one of the latest studies commissioned by the European Commission which analyses the sources of official data and tries to integrate them in order to give a picture of the European framework that is as homogeneous as possible. A difference in per capita sewage sludge production may exist between old and new member states since a different level of implementation of the Urban Wastewater Treatment Directive (UWWTD) can be observed. The UWWTD, which regulates the treatment to be dispensed to the wastewater from municipal and industrial origins, obliged all EU member states to connect all the agglomerations of more than 2,000 person equivalent to systems for the collection and treatment of municipal wastewater (Article 3 of EC Directive, 1991). The deadline for the implementation of the directive in old EU-15 was 2005, while for the new EU-12 some of the transitional periods that were granted on the basis of the size of agglomerations and the nature of the discharge area are still in force. As a result, EU-15 has achieved a 97% compliance rate of the directive, while EU-12 is still far from reaching the final objective, being at 72% of compliance rate: in particular, nine countries has achieved the maximum compliance rate so far, 18 countries have levels of collection beyond 95% of compliance, while only five countries (all EU-12) collect less than 50% of the load that should be collected (Umweltbundesamt GmbH, 2012).

Since the improvement of collecting and treatment systems for wastewater in a country leads to the increase of annual sludge production (LeBlanc et al., 2008), a further increase of the total sludge production in Europe is expected in the upcoming years in EU-12, while in EU-15 the implementation of UWWTD has already led to a 50% increase of annual sewage sludge production from 1992 to 2005 (Kelessidis and

Stasinakis, 2012). It is therefore urgent to find a solution to the problem of sewage sludge disposal, which has faced increasing issues in the EU member states in the last years.

Sewage sludge disposal routes should be designed coherently with the waste hierarchy introduced by the Waste Framework Directive (EU Directive, 2008), which indicates an order of preference for action to reduce and manage waste, i.e., prevention, minimisation, reuse, recycling, energy recovery and, as final and undesired option, landfilling. The amount of sewage sludge disposed of in landfills is intended to rapidly decrease in upcoming years, since the Landfill Directive (EC Directive, 1999) obliges the member states to reduce the amounts of biodegradable waste (and, so, of sewage sludge, which is a biodegradable waste) sent to landfill to 35% of 1995 levels by 2016. This implies that no significant amounts of sewage sludge are expected to going regularly to landfill in the EU-27 by 2020 (Milieu Ltd et al., 2008).

The most favoured route for sludge management in Europe is the reuse of sewage sludge on land, which is regulated by the Sewage Sludge Directive (SSD). SSD (EC Directive, 1986) was developed with the double purpose to safeguard human beings and the environment against the harmful effects from the uncontrolled spreading of sewage sludge on agricultural land and to promote a sustainable use of sewage sludge on land (ESWI, 2012).

Finally, as regard the energy recovery from sewage sludge, incineration and co-combustion are ones of the most common disposal routes in some EU-15 countries (Fytili and Zabaniotou, 2008), but they encounters high investment costs and is not always welcomed by citizens. In the last years, innovative system has been developed to favour sewage sludge thermal treatment (Rada et al., 2014; Bianchini et al., 2015), which is the pre-condition for a more efficient energy valorisation of sewage sludge through innovative routes like pyrolysis or gasification (Manara and Zabaniotou, 2012; Samolada and Zabaniotou, 2014). At the same time, also biological treatment of sewage sludge through anaerobic digestion and/or co-digestion with other organic waste has been applied, especially in northern Europe (Münster and Lund, 2009; Iacovidou et al., 2012; Venkatesh and Abdi Elmi, 2013). SSD provides a great flexibility in national implementation; therefore, a great variety in approaches and limit values chosen by each Member State are encountered. As an example, for heavy metals in sludge and maximum annual loads of heavy metals some countries have set the lowest limits indicated by the directive, while limits for certain metals (such as mercury, lead and chromium) in some countries are even some order of magnitude lower than those provided by the SSD (ESWI, 2012). Gaining an overall perspective, Scandinavian countries can be generally found in the group of lowest limit values, while Mediterranean countries generally adopt the limit values proposed by SSD (Kelessidis and Stasinakis, 2012). The lowering of the pollutants limits in agriculture reuse of sewage sludge made as an independent initiative by some countries has led the European Commission (EC) to put into question SSD in the last decade, thus starting a process of revision and upgrading which will presumably result in the introduction of more stringent limits in the next years (EC, 2010), in particular for Cd, Hg, Pb and Cr. The complete ban of the use of untreated sludge is also expected, such as the determination of a minimum level of stabilisation and of sanitisation of sludge. By considering the described dynamic of sewage sludge European framework, characterised on one side by the carrying out of existing normative and, on the other side, by a public discussion about relevant implementation of SSD in short-medium term, a full knowledge of sewage sludge production and disposal trends clearly appears as an indispensable tool to design an efficient and effective sewage sludge management system. More in general, better knowledge of complete waste cycle dynamic is essential to develop efficiency and reliable waste management system and to reach the objectives of more efficiency and lower impacts on environment and costs (Bianchini et al., 2011).

The aim of the paper is to analyse the way numerical data on sewage sludge quantities are recorded, processed and then reported at EU level to verify the quality of European management informative system. First of all, data from different sources (Eurostat and EC reports) are compared in order to evaluate if discrepancies and incongruities may merge. The second step aims to verify if Eurostat data about sewage sludge production and disposal are consistent. The third and final step analyses current sewage sludge management models in Europe and the impact of legislative implementation on these models.

2 Data used

Eurostat is the main source of data about sewage sludge management in Europe, since it provides statistical information to the institutions of the EU (in particular, policy and decision makers) and also promotes the harmonisation of statistical methods across member states. Eurostat realised two relevant studies regarding sewage sludge (Eurostat, 2014a, 2014b). In both cases, data are collected biennially by means of questionnaires and the operational sources of the data are the National Statistical Institutes, on which no specific data collection is imposed. Data about Croatia was not considered due to its recent EU joining (2013).

In addition, Eurostat data can be integrated by data coming from the EC reports commissioned to analyse the implementation of EU directives in member states. In particular, one report investigates the EU member states compliance rates of the UWWTD as concerns collection of wastewater (EC, 2013). Data source are national relevant authorities or bodies, while data are collected through a centralised informative system called ‘Eionet’, managed by the European Environmental Agency. Another report analyses sewage sludge production and disposal in Europe to verify SSD implementation realised by member states (ESWI, 2012). Latest data refer to 2009 and have been collected in compliance with Article 10 of SSD, which obliges member states to ensure that up-to date records are kept, registering the quantities of sludge produced and used in agriculture, the composition and properties of the sludge, the type of treatment carried out and the recipients of the sludge and the place where it should be used. These records, according to Article 17 of SSD, should be sent to competent authorities at intervals of three years in the form of a sectoral report drawn up on the basis of an outline drafted by the EC.

3 Results and discussion

Table 1 shows the comparison between UWWTD implementation data coming from Eurostat and EC report (Eurostat, 2014a; EC, 2013). EC report computes the national compliance rate to UWWTD Article 3, which means the percentage of agglomeration of more than 2,000 person equivalent connected to wastewater treatment systems. In some cases the year reference is not the same: EC data always refers to the biennium

2009/2010, so the Eurostat data nearest to 2009–2010 has been chosen for the comparison.

Table 1 Comparison between EC report and Eurostat about UWWTD implementation

EU country	*National compliance rates (%) as concerns collection of wastewater (EC, 2013)*		*Population (%) covered by wastewater treatment plants (Eurostat, 2014a)*	
	Percentage, %	*Year*	*Percentage, %*	*Year*
Austria	100	2009/2010	94	2010
Belgium	78	2009/2010	73	2009
Denmark	100	2009/2010	90	2010
Finland	100	2009/2010	83	2011
France	96	2009/2010	80	2004
Germany	100	2009/2010	96	2010
Greece	100	2009/2010	88	2011
Ireland	100	2009/2010	63	2011
Italy	87	2009/2010	Unknown	-
Luxembourg	100	2009/2010	95	2011
Netherlands	100	2009/2010	99	2010
Portugal	97	2009/2010	71	2009
Spain	98	2009/2010	96	2010
Sweden	100	2009/2010	87	2010
UK	100	2009/2010	97	2010
Bulgaria	15	2009/2010	56	2011
Cyprus	0	2009/2010	30	2005
Czech Republic	100	2009/2010	78	2011
Estonia	30	2009/2010	82	2011
Hungary	100	2009/2010	73	2011
Latvia	0	2009/2010	65	2007
Lithuania	100	2009/2010	73	2011
Malta	100	2009/2010	100	2011
Poland	97	2009/2010	66	2011
Romania	Unknown	-	40	2011
Slovakia	100	2009/2010	60	2011
Slovenia	32	2009/2010	56	2011

National compliance percentage should be higher or, at least, equal to the percentage of population covered by wastewater treatment plants, since the first one considers only agglomeration over 2,000 person equivalent, while the second accounts all the population, therefore also agglomeration under 2,000 person equivalent. Incongruities can be found only in EU-12 group, namely Bulgaria, Cyprus, Estonia, Latvia and Slovenia, which show population percentage coverage over national compliance to UWWTD: these discrepancies can be explained by a most recent application of UWWTD, which may lead to wrong data management and/or communication. If compared with EU-15, the most recent application of UWWTD in EU-12 can also explain why EU-15 countries reached a mean compliance rate over 95%, while in EU-12 the mean compliance rate is around 70%, that means that in short-medium term a constant and relevant increasing in population covered by wastewater treatment plant can be expected. Moreover, if data are analysed country by country, another relevant issue comes to attention, i.e., for countries where compliance rate to UWWTD is near or equal to 100%, but percentage of population covered by wastewater treatment plants is under 90%. For these countries, the implementation of UWWTD is substantially complete, but margin still exists to further increase the capacity of the wastewater treatment. In this case, the only way to increase the whole treatment capacity is to realise Wastewater Treatment Plant (WWTP) also in agglomeration under 2,000 person equivalent. A new European policy may be implemented moving towards this objective, but a deep techno-economic analysis is needed to evaluate if the application of UWWTD to agglomerate under 2,000 person equivalent can be reliable or not.

Table 2 shows the comparison between SSD implementation data coming from Eurostat and EC report: both documents contain data about sewage sludge production. Table 2 also compares these data by matching sewage sludge production in the same year (or in the previous closest year, if data are not available), thus showing the absolute variation and the percentage variation computed with EC report data at denominator. In some cases the year reference is not the same, so the data referred to the nearest years has been chosen for the comparison.

For seven countries the computed values are the same, while in ten countries the percentage variation stays under ±10%, which may considered as acceptable. On the other hand, in nine countries a difference over 10% can be observed, with two peaks of variation over 100% for Austria and Portugal. As a result, a high degree of incongruity can be observed in 37% of European countries between the data collected by EC questionnaires (which are the data source of the EC report) and the data collected by Eurostat. Moreover, incongruity is more diffused in the EU-15 (seven countries) than in EU-12 (two countries). A relevant literature exists about the inhomogeneous and contradictory nature of official data about sewage sludge production and disposal in EU (Fytili and Zabaniotou, 2008; Jacobsen et al., 1997; Kelessidis and Stasinakis, 2012), thus supporting Table 2 incongruities, but up to now no relevant actions have been put in place to improve the data management system.

The first major issue is that certain key-terms in the SSD are (or can be) interpreted differently country by country. A clear example is the definition of sewage sludge DM. All data about sewage sludge production and disposal routes, and also pollutants concentration are referred to sewage sludge DM, but in SSD there is no definition of DM and no reference to a technical standard. International reference could be found starting from 1993 (ISO 11465, 1993), while a European standard (CSN EN 12880, 2000) was published later, followed by the current standard in 2012 (CSN EN 15934, 2012). Thus, for example, sewage sludge production in Lithuania was computed as 242 tons DM in 2001 and 66 tons in DM (Eurostat, 2014b): the 73% reduction in sewage sludge production can only be explained by a correction of DM evaluation (UN, 2013). A clear and standardised definition of key-terms, as well as of methodologies and procedures from sewage sludge generation up to sewage sludge disposal is essential to ensure homogeneous and consistent data. So, a further effort is needed to frame the activities of national data reports within common European standard procedures: in this sense, a revision of the SSD targeted to a clearer and more precise definition of all keywords is fundamental.

Table 2 Comparison between EC report and Eurostat about SSD implementation

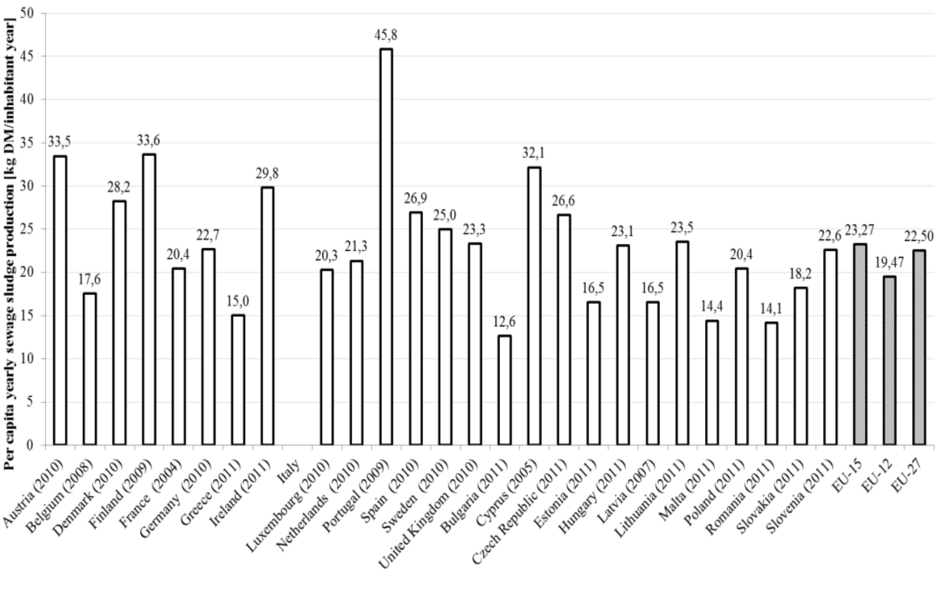
EU country	*Sewage sludge production (ESWI, 2012)*		*Sewage sludge production (Eurostat, 2014b)*		*Variation ktons DM/year*	*%Variation ESWI*
	ktons DM/year	*Year*	*ktons DM/year*	*Year*		
Austria	120	2009	254	2008	134	+111.7
Belgium	139	2009	140	2008	1	+0.1
Denmark	132	2007	140	2007	8	+6.0
Finland	144	2008	144	2008	0	0
France	1,124	2009	1,087	2008	37	–3.3
Germany	1,821	2009	1,958	2009	137	+7.5
Greece	152	2009	152	2009	0	0
Ireland	107	2009	88	2007	19	–17.8
Italy	934	2009	1,056	2005	122	+13.1
Luxembourg	10	2008	13	2008	3	+30.0
Netherlands	500	2009	350	2009	150	–30.0
Portugal	144	2009	344	2009	200	+138.9
Spain	1,205	2009	1,205	2009	0	0
Sweden	212	2009	212	2009	0	0
UK	1,495	2009	1,761	2009	266	+17.8
Bulgaria	40	2009	39	2009	1	–2.5
Cyprus	9	2009	9	2009	0	0
Czech Republic	225	2009	207	2009	18	–8.0
Estonia	22	2009	22	2009	0	0
Hungary	186	2009	149	2009	37	–19.9
Latvia	23	2009	22	2009	1	–4.3
Lithuania	51	2009	50	2009	1	–2.0
Malta	Unknown	-	6	2011	-	-
Poland	562	2009	563	2009	1	+0.2
Romania	125	2008	79	2008	46	–36.8
Slovakia	59	2009	59	2009	0	0
Slovenia	29	2009	27	2009	2	–6.9

The development and realisation of plants and infrastructures for wastewater and sewage sludge directives implementation should be accompanied by a contextual upgrade of informative infrastructures. But a further issue producing inconsistencies in sewage sludge data is that relevant information for monitoring and control of disposal routes as well as for estimating actual pollutant loads of sewage sludge are only available at the local, and not national, administration levels. A case in point can be considered the Italian data management system (Mininni and Sagnotti, 2014), where relevant problems exist in the data communication process between Regions and Environment Ministry, in particular regarding the production level of sewage sludge. In fact, some Italian Regions communicated wrong data (tons not referred to DM) or, at least, no data were produced.

Computerised inventories with data for wastewater collection and treatment, as well as sludge production, reuse and disposal are fundamental to connect the regional and local authorities with the national ones, which are the data sources of Eurostat. To allow a more flexible aggregation and statistical analysis of the data at the European level and, at the same time, to reduce the reporting work load on the member states, a common standard should be designed to develop a reliable and sustainable data management model to be applied at a national level. The revision process of the SSD should include also the definition of a standardised process for data management at national level. Moreover, also the investment in tools and staff training should be at the core of the action of the EU policy in the implementation of SSD, in order to promote a full development of information infrastructures where not yet present. The implementation of management system should also include an increasing in data collection frequency, rising from biennial to annual, at least.

Figure 1 shows the analysis of yearly per capita sewage sludge production in Europe (Eurostat, 2014a). Sewage sludge is a by-product of wastewater treatment processes, so the quantity produced is directly influenced by the percentage of population covered by wastewater treatment plants. Sewage sludge per capita production in one country, measured in kg of DM per inhabitant, has been computed as the ratio between national sewage sludge production (in kg DM) and number of inhabitants, further divided by the percentage of population covered by wastewater treatment plants (Table 1, data from Eurostat, 2014a). The reference year for each country is indicated in Table 1; it may be different from one country to another due to lack of data.

Figure 1 Yearly per capita sewage sludge production in Europe



Source: Elaboration of data from Eurostat (2014a)

As expected, due to more recent application of UWWTD in EU-12, mean EU-15 yearly per capita sewage sludge production results higher than the one in EU-12 of about 20%. If this cause of differentiation is excluded, as well as if the distortion created by the data management systems which, as previously illustrated, are far from being optimised, the deviations from the mean value of sewage sludge per capita production can be brought back to local phenomena, more or less consistent, of assimilation and management in urban treatment plants of wastewater coming from industrial sources. This is another important issue to be clarified in a future review of UWWTD and SSD, i.e., how to compute contribution to sewage sludge production coming from non-urban facilities which are treated by urban wastewater treatment plants.

Table 3 Production and disposal routes of sewage sludge in Europe

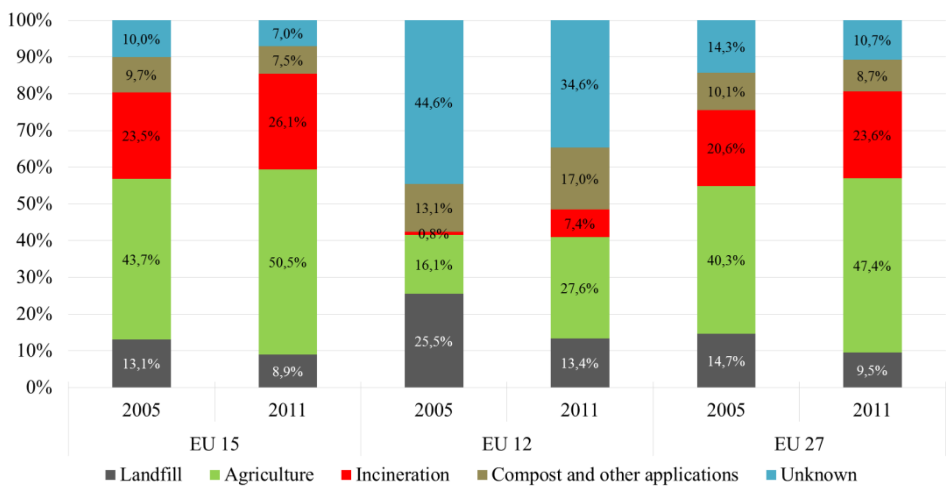
Country (year)	*ktons DM/year*					
	Production	*Landfill*	*Agriculture*	*Incineration*	*Compost and other applications*	*Difference (relative %)*
Austria (2010)	263	21	44	115	83	0 (0%)
Belgium (2010)	176	0	17	113	0	46 (26%)
Denmark (2010)	141	1	74	34	0	32 (23%)
Finland (2009)	149	4	8	0	133	4 (3%)
France (2010)	966	42	727	181	0	16 (2%)
Germany (2010)	1,780	0	566	1004	317	–107 (6%)
Greece (2011)	147	80	6	36	0	25 (17%)
Ireland (2011)	86	0	58	0	28	0 (0%)
Italy (2010)	1,103	462	316	37	0	288 (26%)
Luxembourg (2010)	10	0	5	1	0	4 (40%)
Netherlands (2010)	351	0	0	330	0	21 (6%)
Portugal (2009)	344	22	226	0	0	96 (28%)
Spain (2010)	1,205	96	995	62	0	52 (4%)
Sweden (2010)	204	8	50	2	65	79 (34%)
UK (2010)	1,419	9	1118	260	0	32 (2%)
Bulgaria (2011)	52	28	18	0	1	5 (10%)
Cyprus (2010)	8	0	7	0	0	1 (13%)
Czech Republic (2011)	218	14	108	7	73	16 (7%)
Estonia (2011)	18	2	1	0	15	0 (0%)
Hungary (2011)	168	2	78	30	43	15 (9%)
Latvia (2009)	22	2	8	0	0	12 (55%)
Lithuania (2011)	52	0	10	0	11	31 (60%)
Malta (2011)	6	6	0	0	0	0 (0%)
Poland (2011)	519	51	116	42	31	279 (54%)
Romania (2011)	114	54	2	0	0	58 (44%)
Slovakia (2011)	59	8	0	0	38	13 (22%)
Slovenia (2011)	26	2	0	15	2	7 (27%)

Source: Eurostat (2014b)

Table 3 shows data about production and disposal routes of sewage sludge in Europe. The right column shows the difference between the sewage sludge produced and the one disposed (distinguished in landfill, agriculture, incineration and compost plus other applications).

The difference is equal to zero only in three countries, while in the others one (about 90% of EU countries) a difference can be observed (i.e., more or less sewage sludge produced than disposed). Germany is the only country which has a negative difference (i.e., more sewage sludge disposed than produced). The negative difference computed for Germany can be explained by the importation of sewage sludge from other European countries, Scandinavian in particular. The sewage sludge export, instead, may explain only a marginal amount of the positive difference computed in the other countries. Another possible cause for the positive differences is sewage sludge short-time storage (i.e., some months between production and final disposal) but, once again, this should explain a marginal amount of the positive difference computed, mainly due to biological degradation of sewage sludge. Long-time storage of sewage sludge occurs when the sludge is accumulated near the WWTP since there is no prevision of reusing the sludge produced by the WWTP (Suchkova et al., 2010): the result is that temporary (short-time) storage becomes permanent storage. The filled-to-capacity storage plots remain unused for such a long period that in time turn into grassland, up to the point that recently sludge storage in facilities colonised by plants, usually the common reed *Phragmites communis*, has been suggested as a means of resolving the problem (Pempkowiak and Obarska-Pempkowiak, 2002). In the case of long-term storage, the amount of sewage sludge may be fully stolen from the official amount, since even it is practically realised as a sludge landfilling or land spreading, it may not be officially computed as landfilling or agriculture reuse. It is not acceptable that a so relevant portion of sewage sludge, which is globally equal to 1,025 ktons DM per year (about 11% of total production), has an unknown disposal routes. Once again, SSD should be reinforced in order to better evaluate and compute sewage sludge streams, also considering import-export, short-time and long-time storage, if present.

Figure 2 Sewage sludge disposal routes in EU-15, EU-12 and EU-27 in 2005 and 2011 (see online version for colours)



The previous analysis shows how sewage sludge data about production and disposal routes should be used very carefully: in particular, only consideration about general trends in both production and disposal can be made. Figure 2 shows sewage sludge disposal routes in EU-15, EU-12 and EU-27 from 2005 to 2011; the latest data (Eurostat, 2014b) have been considered. Percentage is referred to the total production.

Two main considerations can be produced among others through the analysis of Figure 2:

1 unknown disposal in EU-12 is too high to make a consistent analysis

2 agriculture is the preferred disposal route in EU-15 and EU-27.

Data analysis demonstrates how future modification of SSD, in particular if concerning sewage sludge agriculture reuse restriction, can have a relevant impact from an environmental and economic point of view on EU countries.

Due to application of both Landfill Directive and SSD, between 2005 and 2011 the amount of sewage sludge sent to landfill has remarkably decreased both in EU15 and EU12, while at the same time an increasing in agriculture reuse can be observed. The observed decrease in the amount of unknown disposal of sewage sludge (which is, however, still remarkable in the new member states) underlines how the improvement of the data management system is already in place, but with a rate of implementation not sufficient to bring the system to conditions of high reliability.

4 Conclusions

Better knowledge of complete sewage sludge cycle dynamics could allow EU countries to reach the sustainability and efficiency goals that are at present still far from being achieved. The paper demonstrates that the EU management system for sewage sludge data shows relevant and structural lack of homogeneity and reliability. Some possible solutions to increase information quality and quantity are suggested to European policy makers and detailed in the paper:

- clear and standard definition of key-terms (for example, sewage sludge dry matter)
- national informative infrastructure upgrade (for example, full computerisation of protocols and data management systems, standardisation and implementation of informative platform used for data collection), also through incentive and direct financing from EU
- annual frequency (at least) of European and national report about sewage sludge management
- definition of standard protocol for data management at a national level, with particular attention to the relation between local and national authorities
- definition of a methodology to assess and evaluate how industrial wastewater assimilation and treatment within urban wastewater treatment plant can impact on sewage sludge production
- include import-export, short-time and long-time storage as sewage sludge disposal routes.

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