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ENVIRONMENTAL IMPACTS OF SEWAGE SLUDGE TREATMENT AND DISPOSAL ROUTES: A LIFE CYCLE ASSESSMENT PERSPECTIVE

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Abstract

This paper aims to assess the main French sludge treatment and disposal routes using Life Cycle Assessment in order to highlight which system is the most suitable from an environmental point of view. System boundaries include thickening up to the disposal route and the functional unit is “one dry matter ton of treated and disposed sludge”. Results are provided for thickening, dewatering and stabilization processes coupled with a disposal route. Major points highlighted by this study are the strong impact of the hypotheses used on LCA results as well as the necessity to produce data to fulfil the inventory step.

Keywords: sewage sludge, sludge treatment, valorization, life cycle assessment, environmental impacts

INTRODUCTION

During the last 20 years, European directives were established to obtain a good quality of aquatic systems. Those regulations aiming at protecting the environment from the adverse effects of the collection, treatment and discharge of waste water and maintaining and improving the aquatic environment were adapted in French laws leading to consequences on sewage treatment. The quantities of sewage sludge produced by the 19750 wastewater treatment plants (WWTP) in France slightly increase to reach 1 100 000 dry matter tons in 2007. Sewage sludges are treated through dewatering, stabilization and sanitization with different technologies depending on WWTP capacity and final disposal route. Four disposal routes are currently possible in France: 70% of sludge is spread on agricultural soils (directly or after composting), 20% is incinerated (dedicated incineration and with household waste) and the last 10% is landfilled. The technologies involved in both sludge treatment and disposal routes have different energetic costs and variable consequences on the environment as it can constitute up to 40% of total emissions of the whole WWTP [1]. As environmental impact associated with sewage sludge is likely to influence public opinion and municipal decision-making [2], understanding the environmental impacts of different sewage sludge management practises is therefore a big concern to choose the appropriate alternative in sludge treatments or disposal routes. This paper aims to compare different sewage sludge management scenarios and their environmental impacts by using the Life Cycle Assessment (LCA) method.

MATERIAL & METHODS

LCA is a common tool to assess environmental impacts of a product or a system. The process or product life cycle is assessed from raw material acquisition through production, use and disposal in a "cradle to grave" perspective. Each step of the life cycle consumes energy, depletes non-renewable resources and produces air, soil and water emissions at different scales (local, regional or global scale). According to ISO14040 standards [3], Life Cycle Assessment is conducted through a four step procedure including (i) goal and scope definition, (ii) life cycle inventory, (iii) life cycle impact assessment and (iv) interpretation.

Goal and scope definition

The goal and scope definition step includes the description of the analysed system, the definition of system boundaries and the definition of an adapted reference unit called functional unit, representative of the system functions and to which all the inventory data should refer.

Our study aims to identify the environmental impacts of sewage sludge treatment and disposal routes in order to highlight which system is the most suitable from an environmental point of view. A focus was done on the part of each process in the whole impact for each studied scenario so as it will be possible to identify which processes need to be improved.

The functional unit (FU) represents the quantification of system functions under study and serves as basis for the calculations and the comparison of the studied scenarios. Traditionally, FUs are expressed in terms of system output. In our case, as we focus our scope on the analysis of a waste management system (i.e. the sludge, considered as a waste from the water treatment plant), our FU is based on the system input: the waste to be managed. In order to fulfill the function of our system (i.e. to treat and dispose sludges according to different treatment processes and disposal routes), our chosen FU is **one ton of dry matter sludge treated and disposed for a WWTP of x population equivalent (PE) during one year**.

The system boundaries are limited to the sludge line, started with the thickening up to the disposal routes (Figure 1).

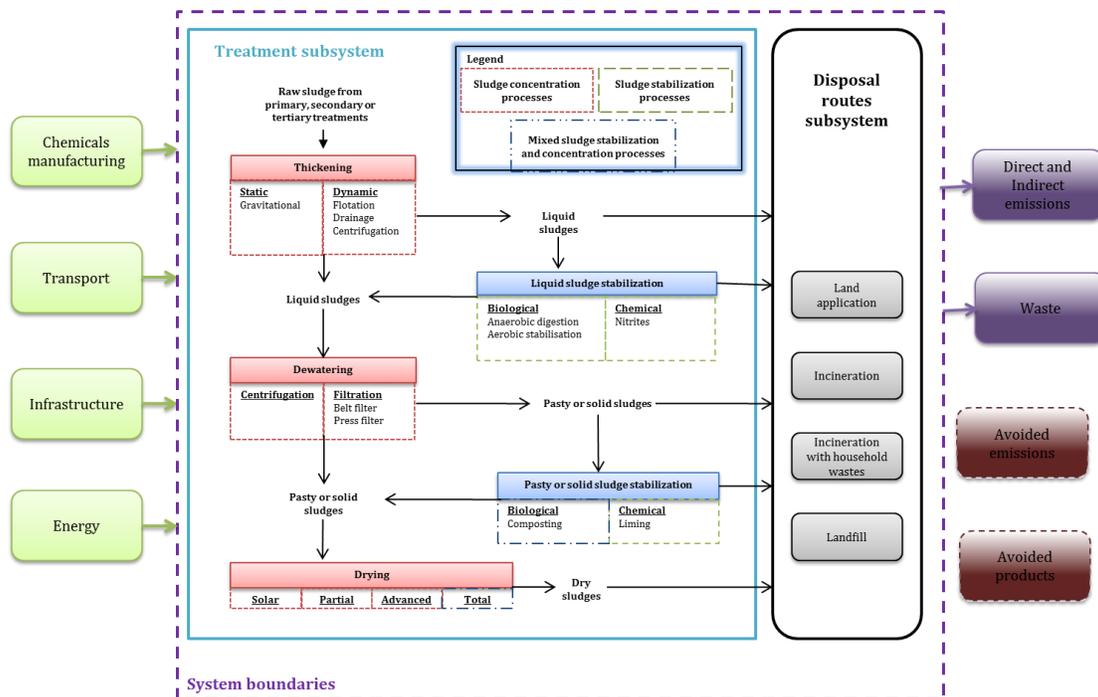


Figure 1. System boundaries

The system is divided in 2 sub-systems: a sub-system for sludge treatment and a sub-system for sludge disposal. Each subsystem is made of different unit representing either a treatment process (Table 1) or a disposal routes (Table 2). Detailed boundaries for each unit can be found in [4-5].

Direct, indirect and avoided emissions are considered. **Direct emissions** directly originate from sludge treatment processes or disposal routes with a distinction done between emissions due to the sludge (biological degradation...) and the other ones (emissions during fuel combustion or electricity consumption needed to run the different sludge treatment processes or occurring in sludge disposal). **Indirect emissions** are due to energy and chemical consumptions (combustible or electricity) to operate each process. Transport emissions (for consumables, sludges and ashes) and civil engineering emissions

are also taken into account. **Avoided emissions** are accounted when processes are substituted by other processes and can be generated by energy or material substitutions: (i) Thermal or electric energy production from biogas – avoided emissions are due to emissions that will have taken place for an equivalent non-renewable amount of energy, (ii) Use of sludge as fertilizers – avoided emissions are those generated by the amount of substitute mineral fertilizer production and its spreading.

Table 1. Units involved in the sludge treatment subsystem and chosen hypotheses

Subsystem	Units		Hypotheses regarding the dry matter reduction
Sludge treatments	Storage	Temporary storage 3 months storage	None
	Thickening	Gravitational	5%
		Flotation, Drainage, Centrifugation	10%
	Dewatering	Centrifugation	5.5%
		Belt or band filter	5%
Press filter		3.5%	
Stabilisation	Anaerobic digestion	35.33% (62% volatile matter)	
	Aerobic digestion	19.83% (32.90% volatile matter)	
	Composting	57% (45% volatile matter)	
	Liming	0%	
Drying	Solar	30%	
	Thermal	20%	

Table 2. Units involved in the sludge disposal routes subsystem and chosen hypotheses

Subsystem	Units	Hypotheses
Disposal routes	Dedicated Incineration	Transport is modelled only for incineration with household wastes. Heat and energy produced are recovered and reused on-site which generate avoided emissions. By-products such as residues from flue gas treatment are landfilled while fly ashes are either landfilled or valorised in road construction.
	Incineration with household wastes	
	Landfill	Sludge emissions from landfill are supposed to be identical than emissions for sludge mixed with household wastes from whom data are available in literature. The modelled landfill is 10 years-old with a collection rate of 95% for leachates and 90% for biogas. An estimation of 10% of biogas leak is assumed. The collected biogas is either used in a heater generating avoided emissions or burnt in a flare.
	Land application	Using sludge as an agricultural fertiliser generates avoided emissions. In our system, we modelled avoided mineral fertilisers and the nitrogenous associated emissions and phosphorous emissions.

As multiple scenarios can be created as there are many sludge lines as WWTP in France, we built 9 scenarios representing the most encountered sludge lines in France and for whom data can be easily collected (Figure 2).

Sludge in scenario LSS to DewDSS is thickened by gravitational thickening and either spread directly without any other treatment (scenario LSS) or digested through anaerobic digestion. The digested sludge is then either dewatered by centrifugation and then spread in the field with a valorization of the biogas through cogeneration (scenario DSS+biogas) or dewatered by a press filter before land spreading (scenario DewDSS). Sludge in scenario CompDSS to DrySI+HW is thickened by drainage but go through different dewatering process. As scenario DSS + biogas, sludge is digested through anaerobic digestion with a biogas valorization by cogeneration before being dewatered through centrifugation. The dewatered digested sludge is then composted and spread in agricultural field (scenario CompDSS). The sludge is dewatered by band filter before liming and spreading in agricultural field (scenario LimSS(band-drain)). The third dewatering process modeled is a press filter using mineral conditioning before landfilling as we want to model a sludge that is unsuitable for agricultural spreading (scenario DewSL+biogas). Finally, sludge can be dewatered through centrifugation before being either limed and send to a landfill (scenario LimSL+biogas) or thermally dried and burned with household waste in an incinerator (scenario DrySI+HW). Sludge in scenario LimSS(flo-cent) is thickened by flotation before being dewatered by centrifugation and limed and then spread in agricultural fields.

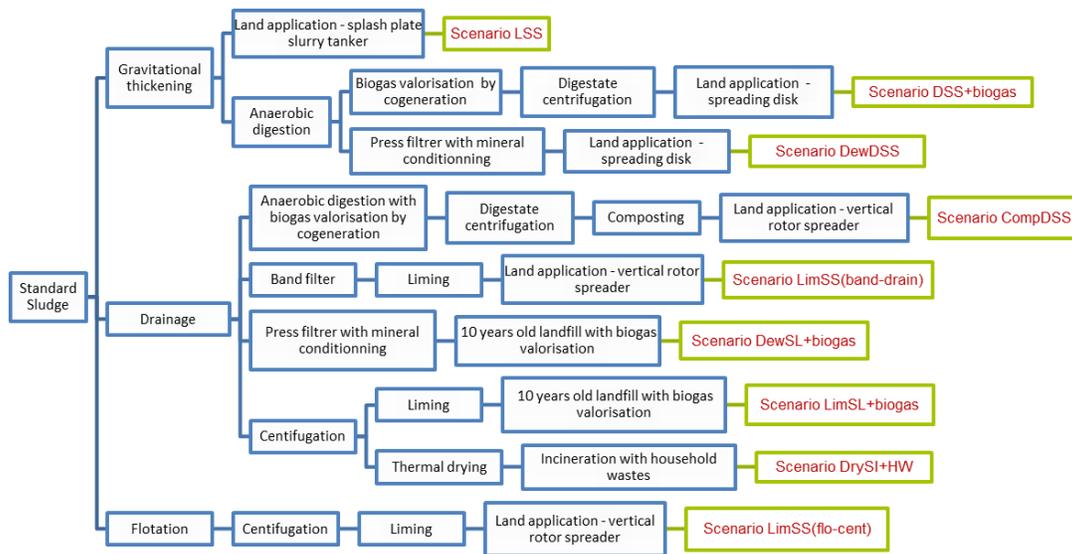


Figure 2. Scenario description

Life Cycle Inventory data

The life cycle inventory (LCI) consists of quantifying all the inputs and outputs data involved in the system. Data quantification is achieved according to the functional unit. Data used come from two different sources: (i) relevant scientific literature for direct emission, chemical and energy used, avoided emission and avoided products and (ii) Ecoinvent (v2) database for transport, French electricity mix, infrastructures and chemical manufacturing. Data are summarized in [6-8]. As many inputs and emissions are involved for each treatment processes and each disposal routes, it is not possible to take an inventory of all of them in this paper. As an example, the inventory data for different dewatering technology is given in Table 3.

SimaPro 8.0 software was used to model the different scenarios and assess their environmental impacts.

Table 3. Dewatering treatment technologies life cycle inventory

		Centrifugation		Press Filter		Band Filter	
		Standard sludge	Digested sludge	Standard sludge	Digested sludge	Standard sludge	Digested sludge
<i>Each value is given for one dry matter ton of sludge (i.e. the functional unit)</i>							
Input							
Electricity, medium voltage, production FR, at grid/FR U	kWh	65.80	50.33	37.00		34.36	35.50
Polymers	kg	5.78	6.65	5.00	6.00	5.50	5.00
Iron (III) chloride, 40% in H ₂ O, at plant/CH U	kg			57.50	60.00		
Lime, hydrated, packed, at plant/CH U	kg			236.88	220.00		
Dewatering technology infrastructure	p	1.49E-04		1.49177E-04		1.49E-04	
Chemical conditioning	p	1.49E-04		1.49041E-04		1.49E-04	
Output (mainly emissions to air)							
Methane, biogenic	kg	12.33					
Dinitrogen monoxide	kg	0.77					

Impact assessment method

The Life Cycle Impact Assessment (LCIA) converts each quantified inventory flow into corresponding environmental impact categories through a characterization factor. Different methodologies can be used to assess environmental impacts. We chose one of the most recent methods: Recipe [9]. Recipe proposes a limited number of indicator scores that express the relative severity on an environmental impact category. To stay simple in the environmental analysis, we will focus only on 8 midpoint indicators among the 21 available indicators as they represent the most interesting impacts to analyze: global warming, human toxicity, aquatic ecotoxicity (fresh water and marine), terrestrial ecotoxicity, acidification, freshwater eutrophication, marine eutrophication.

RESULTS

Climate change

The main contributors to climate change are fossil CO₂, N₂O, CH₄ and SF₆. As shown in Figure 3, at least 60% of the impact on climate change is due to the treatment processes whatever the scenario. Drying (DrySI+HW), liming (LimSS(band-drain), LimSS(flo-cent), LimSL+biogas) and dewatering with press filter (DewSL+biogas) are the most impacting treatment on climate change due to their high electric or thermic energy consumption.

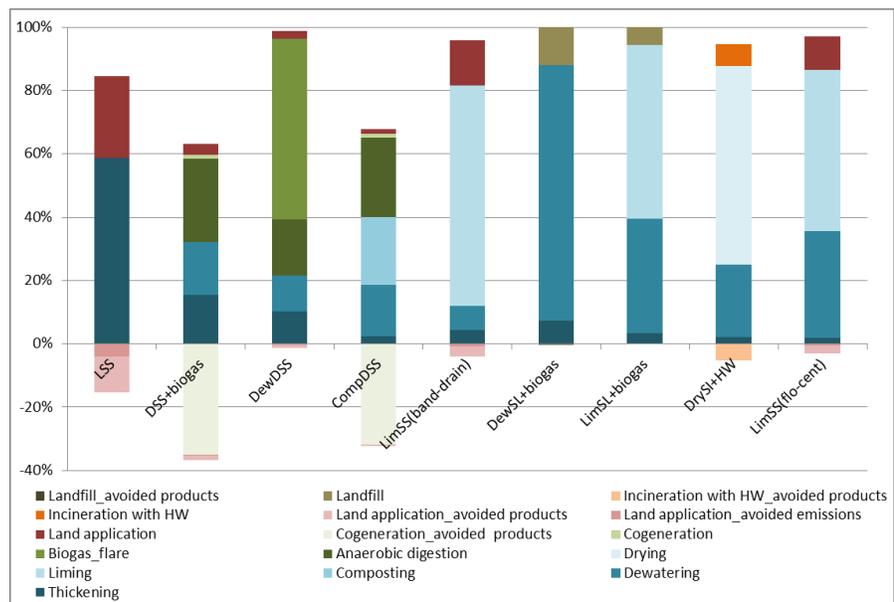


Figure 3. Climate change impact for each scenario

Sludge land application impacts a little more than incineration or landfill but the mineral fertilizers and related emissions avoided had a benefit compared to the two other disposal routes. When anaerobic digestion is modeled (DSS+biogas, DewDSS, CompDSS), the 2% biogas leaks as well as the electricity and heat used represent almost 25% of the impact. When the biogas is collected and reuse, an avoided impact occurs (DSS+biogas, CompDSS) representing almost 30% of the total climate change impact. On the contrary, if flared, the biogas increases the impact on climate change even if all the methane is transformed in CO₂, a 25 times less impacting gas (DewDSS).

Freshwater and marine eutrophication

Freshwater eutrophication is mainly due to the emission of phosphorus in the environment while marine eutrophication is mainly due to nitrogenous emissions. As shown in Figure 4a, land application of sludge generates few phosphorus emissions but avoids the use of mineral fertilizers leading to a negative impact (or a benefit) from 60 up to 90%. The consumption of iron and lime for sludge conditioning before press filter is the most impacting for DewSL+biogas while the leaching of P from the landfill contributes to 25% to the impact of LimSL+biogas. Land application presents a benefit due to the avoided mineral fertilizers for freshwater and marine eutrophication (Figures 4a and 4b). The drying process impacts up to 80% in DrySI+HW due to the emissions of ammonia. In a same manner, liming in LimSL+biogas contributes up to 80% due to the emissions of NO_x and NH₃.

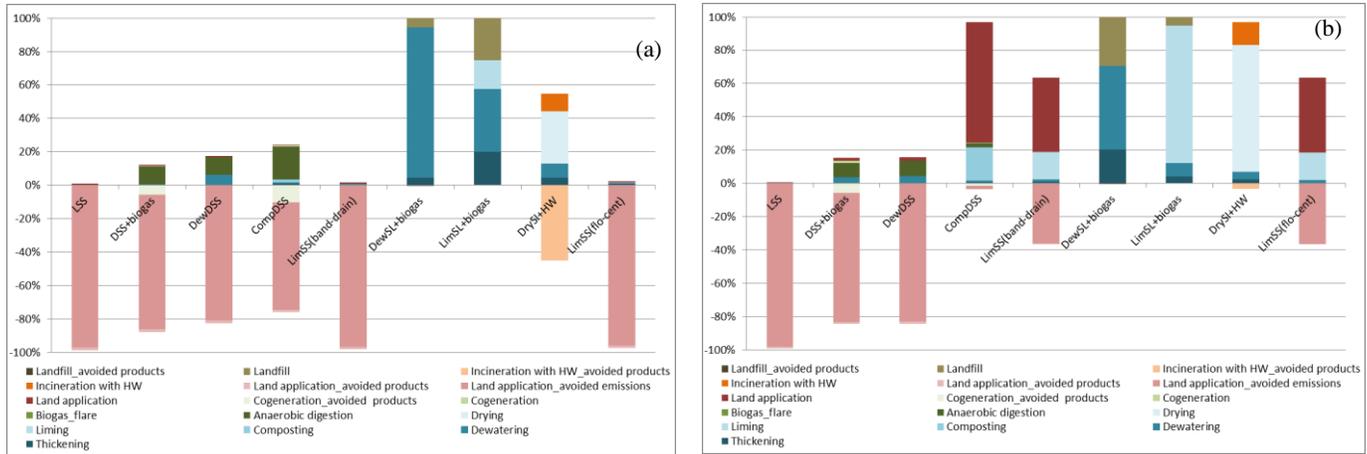


Figure 4. Freshwater eutrophication (a) and marine eutrophication (b) impacts for each scenario

Acidification

Acidification is mainly due to the emission of ammonia, nitrogen oxides and sulfur dioxide in the atmosphere. The main contributors to the acidification impact are therefore the land application which contributes up to 60% for limed sludge (LimSS(band-drain), LimSS(flo-cent)), sludge composting (CompDSS) that represents also 60% of the whole impact and thermal drying (DrySI+HW) due to the emission of ammoniac, and different kind of acids (propionic, acetic, formic) during the combustion

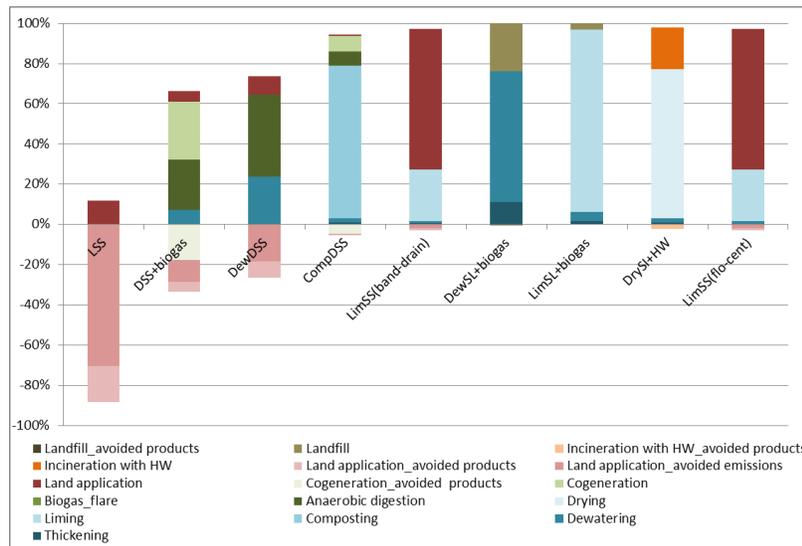


Figure 5. Acidification impact for each scenario

process (Figure 5). Finally, liming generates emissions such as SO₂, ammonia and NO_x that contribute to almost all the impact for LimSL+biogas and only at 25% for LimSS(band-drain).

This is mainly due to the fact that there is no ammonia emission or acid substances released in the atmosphere from the landfill so all the emissions generated for this scenario are from the liming process. Due to its higher content in nitrogen, the liquid sludge spread in LSS avoids the use of mineral fertilizers and the related emissions up to 80%.

Human toxicity and ecotoxicity

As results for toxicity and ecotoxicity are very close, only human toxicity is shown in Figure 6.

Land application in LSS is the main contributor to human toxicity due to the heavy metals contained in the sludge and in a less proportion in LimSS(band-drain) and LimSS(flo-cent) where the avoided impacts are greater due to a higher quantity of mineral fertilizers avoided than in LSS. Anaerobic digestion contribute up to 50% in DSS+biogas, DewDSS, CompDSS due to a high electricity consumption but the electricity

produced with the biogas cogeneration soften its impact on human toxicity.

Finally, the incineration of sludge with household waste contribute up to 100% to the impact due to the emissions of various pollutants such as heavy metals (lead, mercury...), persistent pollutants (dioxins...) or polycyclic aromatic hydrocarbons. The same tendencies are observed with the freshwater, marine and terrestrial ecotoxicities.

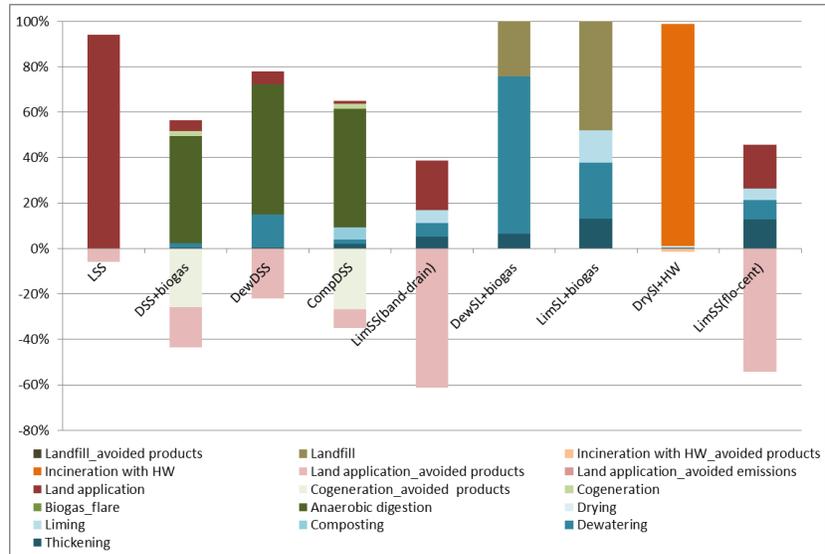


Figure 6. Human toxicity impact for each scenario

DISCUSSION

Scenario comparison based on the most impacting one

To highlight which scenario is better or worse from an environmental perspective, a comparison is needed. Figure 7 shows the most impacting scenario for each impact and the other scenarios are calculated based on this 100% basis.

The most impacting scenario greatly depends on the impact analyzed.

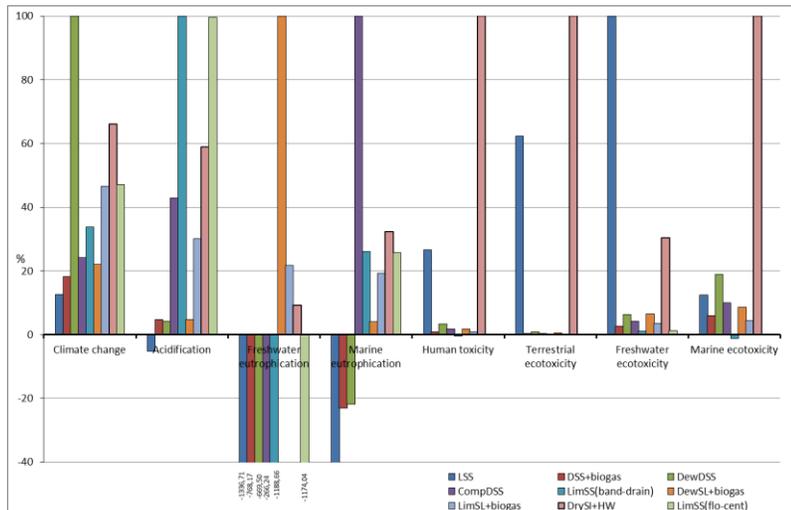


Figure 7. Scenario comparison of each studied environmental impact

Treatment processes

Thickening is the treatment process that has the lowest environmental impact whatever the impact. Differences between thickening technology cannot be distinguished due to the low electricity consumption. This treatment step is negligible from an environmental point of view. Among the three dewatering technologies, press filter dewatering has a highest impact compared to the two others. The impacts are linked to the high quantity of lime and iron chloride used for sludge conditioning before dewatering. Centrifugation and band filter are the best dewatering technologies from an environmental point of view but their dewatering rate is not as efficient as the press filter ones. Among stabilization processes, composting weakness is strong ammonia emissions leading to a high acidification impact while liming strongly impact on climate change due to the lime manufacturing. Anaerobic digestion impacts most categories due to the energy needed to heat the digester but using the biogas produced in a cogeneration process can greatly reduce the latter by the impact it avoids. Sludge thermal drying generates a strong electricity and heat consumption impacting climate change and ammonia emissions that impact on acidification and marine eutrophication. Scenarios using thermal drying are among the most impacting.

Disposal routes

Scenarios involving land spreading impact most than others on climate change, acidification and eutrophication. However, results show great disparities between sludge land spreading according to the type of sludge and the spreading technology used. No nitrogenous emissions (NH₃ and N₂O) were found in literature for liquid and dewatered sludges even though these emissions are generated if sludge contains ammoniacal nitrogen and spreading conditions are not optimal. As these emissions were not recorded for liquid and dewatered sludges, scenarios LSS, DSS+biogas and DewDSS are the most favorable for marine eutrophication than scenarios with composted or limed sludge spreading (LimSS(band-drain), LimSS(flo-cent), CompDSS) for whom these emissions are available in literature. In addition, as limed sludge generates a high quantity of ammonia, scenarios LimSS(band-drain) and LimSS(flo-cent) are the most impacting regarding acidification. As some nitrogenous emissions data provided by literature come from sometimes only one source (such as CH₄ emission after liquid sludge spreading, NO₃ emission after composted sludge spreading, NH₃ emission after limed sludge spreading), results should be considered cautiously.

Scenarios involving incineration emit substances that impacts mainly on human toxicity and ecotoxicities compared to other scenarios but if the energy is recovered and reused, the energy and heat produced generate avoided products (such as French electricity mix or fuel for heating) and related avoided emissions that lightened the impact of incineration. Scenarios simulating landfilling are not the most impacting except for freshwater eutrophication. Landfilling can be a friendly disposal route if only landfills are equipped to treat leachate and recover the produced biogas.

CONCLUSION

This paper provides information on the most environmental friendly sludge treatment and disposal routes scenarios. Each treatment and disposal has their own advantages and drawbacks. The environmental impact of a sludge line is before everything dependent on the way processes are implemented to each other. The inventory life cycle was conducted for each treatment process independently without taken into account the possible interactions between them. By the way, inventory data need to be completed as we miss data to complete the inventory. Regarding sludge land application, this lack of data is focused on nitrogenous emissions. As these emissions are highly dependent on soil and climate conditions [10], it will be better to use biophysical simulation models to assess these nitrogenous emissions rather than data from literature. Finally, hypotheses related to the scenario definition have also a great impact. A sensitivity analysis based on the chosen hypotheses is on-going to quantify the variation occurring in results.

REFERENCES

- [1] Shaw, A. et al., 2010. Workshop Summary: The role of modeling in assessing greenhouse gas (GHG) emissions., Proceedings of 83rd Annual WEFTEC, New Orleans, LA.
- [2] Brown, S., Beecher, N., Carpenter, A., 2010. Calculator tool for determining greenhouse gas emissions for biosolids processing and end use. Environmental Science and Technology 44(24) pp. 9509-9515.
- [3] AFNOR, 2006. NF EN ISO 14040 [Analyse du cycle de Vie - Principes et cadre, 23 pages] and NF EN ISO 14044 [Analyse du cycle de Vie - Exigences et lignes directrices, 49 pages]
- [4] Reverdy, A. L. and Pradel, M., 2012. Bilan environnemental des filières de traitement et de valorisation des boues issues du traitement des eaux usées. Rapport Onema/Irstea, 64 pages.
- [5] Pradel, M., Richard, M., Reverdy, A.L., 2013. Analyses du cycle de vie des filières de traitement et de valorisation des boues issues des eaux usées – Inventaire du Cycle de Vie et principales sources d'optimisation des filières de traitement et de valorisation des boues issues des eaux usées. Rapport Onema/Irstea, 100 pages.
- [6] Reverdy, A. L. and Pradel, M., 2011. Evaluation des émissions de gaz à effet de serre des filières de traitement et de valorisation des boues issues du traitement des eaux usées. Rapport MEDDLT/Irstea, 93p.
- [7] Richard, M., 2013. Analyse du Cycle de Vie des filières de valorisation des boues issues du traitement des eaux usées, Mémoire de fin d'étude EME, 95 pages.
- [8] Chabat L., 2013. Analyse du Cycle de Vie des filières de traitement des boues issues du traitement des eaux usées, Mémoire fin d'études, diplôme d'ingénieur agronome, spécialité GEME, Montpellier SupAgro, 99p.
- [9] Goedkoop, M. et al., February 2013. ReCiPe 2008 - A life cycle impact assessment method which comprises harmonised category indicators at the midpoint and the endpoint level. First edition (revised). Report I: Characterisation. 133 pages.
- [10] Pradel, M., Pacaud, T., Cariolle, M., 2013. Valorization of organic wastes through agricultural fertilization: coupling models to assess the effects of spreader performances on nitrogenous emissions and related environmental impacts. Waste and Biomass Valorization, 4:851–872