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# <sup>o</sup>E<sub>s</sub>TABOUES, a decision tool to assess greenhouse gases of sewage sludge treatment and disposal routes

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## EXECUTIVE SUMMARY

Sewage sludge production increases continuously reaching almost 20% (946 700 tons of dry matters in 2003 to 1 118 795 tons of dry matters in 2007) during the last decade. In 2007, 70% of the produced sewage sludge was spread (directly or after composting). The remaining 30% was incinerated (with or without household wastes) or landfilled. Nowadays, sludge reduction is a major concern. This activity has to become more sustainable and stakeholders have to be careful to the environmental impacts of sludge treatment and disposal routes.

To help stakeholders in that way, we developed a decision tool called <sup>o</sup>E<sub>s</sub>TABOUES. <sup>o</sup>E<sub>s</sub>TABOUES is a tool based on the "Bilan Carbone<sup>®</sup>" method (ADEME 2009). It was developed for stakeholders dealing with wastewater treatment plants (plant manager, public administration...) to quantify greenhouse gases (GHG) for each type of emissions and each process of sludge treatment and disposal routes. The tool was developed with VisualBasic programming language.

This tool can be used in a four step procedure:

- (i) The user built as many wastewater treatment plants (WWTP) he wants. He should specify the WWTP capacity, the type of sewage network and the water treatment system.
- (ii) Then the user creates all the sewage sludge treatment processes used for each WWTP. He has to choose different parameters for each step of sludge treatment and disposal. The user has the opportunity to choose either its own data or data collected through a literature review and implemented as "default value" in the tool.
- (iii) Once each WWTP and the treatment and disposal routes of each WWTP created, the user can choose different graphic presentations to assess the impact of greenhouse gases emissions (Figure 1). <sup>o</sup>E<sub>s</sub>TABOUES calculate all emissions (direct and indirect) of carbon dioxide, methane and nitrous oxide for all steps of sewage sludge treatment (storage, thickening, anaerobic digestion, aerobic digestion, dewatering, alkaline stabilization, composting, drying) and sludge disposal route (land application, incineration, incineration with household wastes, landfilling). Emissions from infrastructures and transports are also considered. These graphs present emissions for each step (thickening, dewatering, land spreading...), each gas (dioxide carbon, methane and nitrous oxide) and each origin of greenhouse gases (combustible, electricity, direct emissions, avoided emissions, infrastructure, chemicals and transport). The graphs can be presented either as values or percentages.
- (iv) Finally, the user can compare different sewage sludge treatment processes and disposal routes options and create reports with Microsoft Word through an export button. Each report summarizes the mass and energy balance as well as the selected graphs to be exported.

In this study, this tool is used to compare 3 systems on a same WWTP to help stakeholders to identify which processes have the worst environmental impact all along the treatment and disposal route, which emission is overwhelming and to help them selected the most interesting system from an environmental point of view.

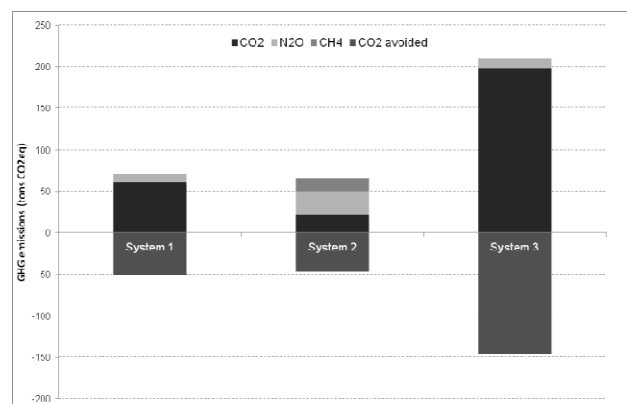


FIGURE 1 Example of <sup>o</sup>E<sub>s</sub>TABOUES results

## **1 INTRODUCTION**

### **1.1 Background**

During the last 20 years, European directives were established to obtain a good quality of aquatic systems. Those regulations adapted in French laws lead to consequences on sewage treatment. In March 2010, there was 18 637 wastewater treatment plants (WWTP) in France treating the pollution of 75 million equivalent inhabitant (equivalent to the charge of 18699 towns) (Golla et al., 2010).

Sewage sludge treatment and disposal can constitute up to 40% of total emissions associated with wastewater treatment (Shaw et al., 2010). A range of different stabilization and end use technologies are widely available, each technology associating different costs and environmental impacts (Brown et al., 2010). Sewage sludge increases continuously and about 1 100 000 tons of sewage sludge were produced in 2008. Sewage sludges are treated (dewatering, stabilization and sanitization) with different technologies depending on WWTP capacity and final disposal route. Four disposal routes are currently possible: 70% of sludge is spread on agricultural soils (directly or after composting), 20% is incinerated and the last 10% is landfilled.

The technologies involved in both sludge treatment and disposal have different energetic costs and variable consequences on the environment and Global Warming. Understanding the greenhouse gases (GHG) emissions associated with different sewage sludge management practises is likely to influence public opinion and municipal decision-making (Brown et al., 2010).

### **1.2 Research objectives**

In order to help stakeholder in their decision making, we develop a decision tool, called <sup>o</sup>E<sub>s</sub>TABoues, to assess the impact on Global Warming of different sewage sludge treatment and disposal routes.

This paper aims to present <sup>o</sup>E<sub>s</sub>TABoues tool which was developed to model and calculate GHG emissions from different sewage sludge treatment processes and disposal routes options. The tool was designed to compare the GHG impact of different sewage sludge management options.

A comparison of 3 sludge treatment and disposal route systems is presented in this paper. One system represent data coming from a real WWTP, the two others are optional systems that could be interesting for the WWTP managers.

The first part of this paper will present the framework of <sup>o</sup>E<sub>s</sub>TABoues. The second part presents the studied systems and the last part how the results impact on Global Warming.

## **2 METHODOLOGY**

### **2.1 <sup>o</sup>E<sub>s</sub>TABoues tool**

The <sup>o</sup>E<sub>s</sub>TABoues tool allows the calculation of the carbon footprint of sludge treatments and disposal routes. The method underlying this tool is explained in Pradel and Reverdy (2012). It is based on the “Bilan Carbone<sup>®</sup>” method (ADEME, 2009), a general method used to quantify GHG generated from all physical processes which are necessary for any activity or human organization. In our method, three GHG are recorded: carbon dioxide (CO<sub>2</sub>), methane (CH<sub>4</sub>) and nitrous oxide (N<sub>2</sub>O). Each gas has his own Global Warming Potential (GWP): 1 for CO<sub>2</sub>, 25 for CH<sub>4</sub> and 298 for N<sub>2</sub>O.

In <sup>o</sup>E<sub>s</sub>TABoues, direct and indirect emissions are considered as well as avoided emissions. This tool doesn't take into account biogenic CO<sub>2</sub> emissions as they belong to the short cycle of carbon and as they are considered (by convention) as “carbon neutral”.

In <sup>o</sup>E<sub>s</sub>TABoues, GHG emissions are quantified for x tons of sludge produced by a wastewater treatment plant of x per-capita equivalent (PCE) during one year.

Default values were defined for each process, including inputs, energy use, chemical consumption and GHG emissions. Data were collected from literature (Pradel and Reverdy, 2012). Emissions and credits for each process were classified as direct emissions, chemicals, electricity, fuels, transport, infrastructure and avoided emissions.

<sup>o</sup>E<sub>s</sub>TABoues tool was developed with VisualBasic programming language. It is made with 4 different windows (Figure 2): WWTP creation, System creation/modification, System comparison, Results export

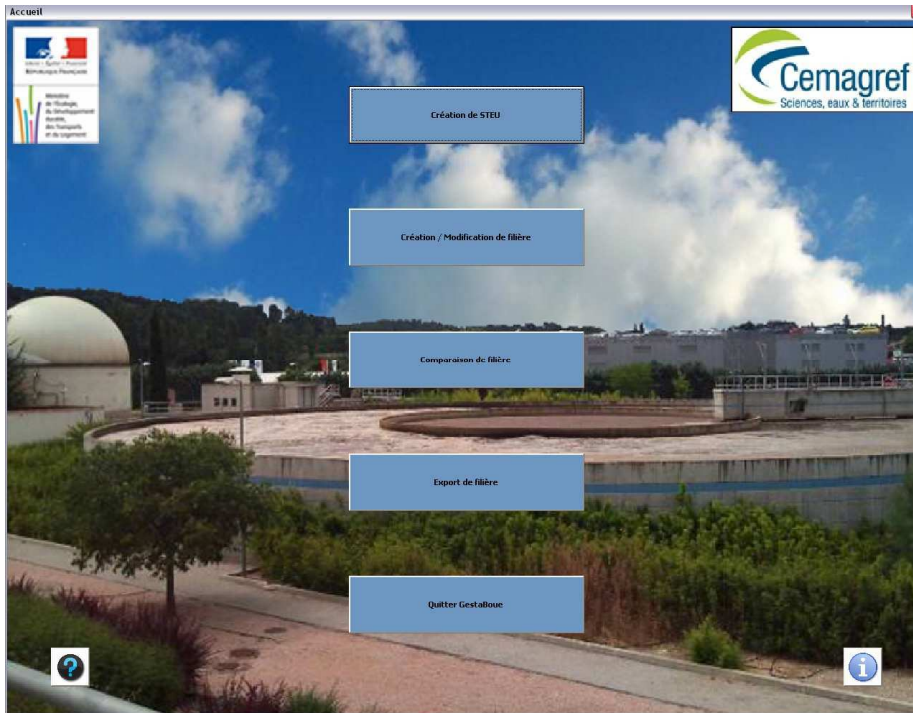


FIGURE 2 G<sub>E</sub>S<sub>T</sub>ABoues main window screen shot

### 2.1.1 WWTP creation

This window is used to create different WWTP with their characteristics. In this part, user can choose the WWTP capacity (in per-capita equivalent), the type of sewer network (combined sewer system, separated sewer system, partially separated sewer system) and the type of water treatment (activated sludge, biological treatment...).

During this step, dry matter quantity of sludge produced is accounted according to 3 methodologies:

- User knows the dry matter quantity and use it (in dry matter ton/year),
- User doesn't know the dry matter quantity but knows BOD<sub>5</sub> and suspended matter quantities (in kg/day),
- User doesn't have any data; dry matter quantity is calculated based on Guérin-Schneider (2001).

### 2.1.2 System creation/modification

During this step, users can create several systems for each WWTP. Each system is composed by different treatments and disposal routes that user can select (Table 1). For each treatment and disposal route selected, a window opens to be completed either with users' values or with default values coming from the literature.

TABLE 1 Treatment and valorisation/disposal routes in GEsTABoues

Treatment	Valorisation/Disposal
Storage	
Thickening ( <i>gravity, flotation, thickening grid, thickening table, thickening drum, centrifugation</i> )	
Anaerobic digestion stabilisation	Land application
Aerobic digestion stabilisation	Incineration
Dewatering ( <i>classical centrifugation, high performance centrifugation, direct centrifugation, belt filter, press filter, sludge dewatering reed beds</i> )	Incineration with household wastes
Liming stabilisation	Landfilling
Composting	
Drying ( <i>thermal, solar</i> )	
Transports, Infrastructures	

At the end of systems creation, <sup>o</sup>E<sub>s</sub>TABOUES takes into account GHG emissions during transports (polymers, sludge, chemicals, ashes ...). A new window opens to be filled by the user for that purpose. Then a window opens to show already calculated GHG emissions from infrastructure (civil engineering and electrical/mechanical equipments).

The next step provides results presented as bar chart graphs. The graphs present emissions for each step (thickening, dewatering, land application...), each GHG (carbon dioxide, methane and nitrous oxide) and each origin of GHG (combustible, electricity, direct emissions, avoided emissions, infrastructure, chemicals and transport). They can be presented either as values or percentages. In Gestaboues, 10 types of bar chart can be shown.

### 2.1.3 Systems comparison

<sup>o</sup>E<sub>s</sub>TABOUES was also designed to compare different systems in order to analyse the best option either in sludge treatment or disposal route. By selected several systems for each WWTP, it is possible to compare them using the same bar charts graphs than for a single use (see “system creation/modification” section).

### 2.1.4 Results export

User can create reports with Microsoft Word trough an export button. Each report summarizes the mass and energy balance as well as selected graphs to be exported.

## 2.2 Studied systems choice

To validate <sup>o</sup>E<sub>s</sub>TABOUES, we choose to test three different systems of a same WWTP. The WWTP has a capacity of 8500 PCE. Sewage is collected with a partially separated sewer network and treated with extended aeration. The WWTP produces around 71 tons of dry matter of sludge during one year.

The WWTP characteristics, the studied systems and the data collected for each system are shown in Table 2.

The first system is the current system of the studied WWTP. The sludge treatment and disposal route system is composed by gravitational thickening, belt filter dewatering, liming and land application. System 2 and system 3 are variants of this system.

We proposed in system 2 to change the stabilization process by replacing liming by composting and in system 3 to change the disposal route by incineration with household wastes so as stabilisation is not any more necessary.

TABLE 2 **Wastewater treatment plant and systems characteristics and inputs in each system**

	System 1	System 2	System 3
Capacity (PCE)		8500	
Network		Partially separated sewer system	
Water treatment		Extended aeration	
Sludge quantity (DM tons)		71.36	
BOD <sub>5</sub> (kg/j)		510	
Thickening		Gravitational thickening	
Dewatering		Belt filter	
Stabilisation	Liming	Composting	-
Disposal	Land application	Land application	Incineration with household wastes (co-incineration)
Polymers (kg)	Thickening = 0 Dewatering = 180	Thickening = 0 Dewatering = 180	Thickening = 0 Dewatering = 180
Electricity (kWh)	Thickening = 713 Dewatering = 1819	Thickening = 710 Dewatering = 1708	Thickening = 710 Dewatering = 1708
Lime (t)	Liming = 44	0	Co-incineration = 923
Co-substrate (t)	0	Composting = 200	0
Coal (kg)	0	0	Co-incineration = 99
Fuel	Land application = 32 L/h	Land application = 33 L/h	Co-incineration = 5

### 3 RESULTS AND DISCUSSION

#### 3.1 System 1

System 1 generates about 71 tons CO<sub>2</sub>eq (all gases merged) during one year. GHG emissions are shared between:

- CO<sub>2</sub> = 61 tons CO<sub>2</sub>eq,
- N<sub>2</sub>O = 10 tons CO<sub>2</sub>eq,
- Avoided emissions = - 51 tons CO<sub>2</sub>eq (-21.8 from mineral fertilisers and -28.9 from carbon sequestration)

TABLE 3 GHG emissions of system 1

Tons CO <sub>2</sub> eq		Treatment and disposal steps				Total
		Thickening	Dewatering	Liming	Land application	
Emission origin	Direct emissions	0	0	0	10.2 (as N <sub>2</sub> O)	10.2
	Chemicals	0	0.77	42.9	0	43.7
	Electricity	0.063	0.16	0.031	0	0.25
	Fuel	0	0	0	0.50	0.5
	Transports	0	9.4	1.1	5.8	16.3
	Infrastructure	0.17	0.20	0.24	0.003	0.61
	Avoided emissions	0	0	0	-50.7	-50.7
<b>Total</b>		0.23	10.5	44.3	16.5 / -50.7	<b>71.5 / -50.7</b>

We can conclude from Table 3 that:

- Thickening emissions are insignificant.
- 90% of dewatering GHG emissions is generated by polymers transport between suppliers and WWTP.
- Liming is responsible to the most important GHG emissions. During liming, more than 95% of GHG are generated by lime production.
- Land application emissions come from N<sub>2</sub>O direct emissions and sludge transport between WWTP and fields.
- Avoided emissions are generated during land application (-50.7 tons CO<sub>2</sub>eq). Avoided emissions are due to the non use of mineral fertilizers and to the carbon sequestration (-0.25 kg CO<sub>2</sub>eq/kg dry matter based on SYLVIS, 2009).

#### 3.2 System 2

65.2 tons CO<sub>2</sub>eq are produced by system 2 and -46.8 tons CO<sub>2</sub>eq are avoided. GHG emissions are shared between:

- CO<sub>2</sub> = 21.9 tons CO<sub>2</sub>eq,
- CH<sub>4</sub> = 15.2 tons CO<sub>2</sub>eq,
- N<sub>2</sub>O = 28.1 tons CO<sub>2</sub>eq.

TABLE 4 GHG emissions of system 2

Tons CO <sub>2</sub> eq		Treatment and disposal steps				Total
		Thickening	Dewatering	Composting	Land application	
Emission origin	Direct emissions	0	0	15.2 (as CH <sub>4</sub> ) 25.0 (as N <sub>2</sub> O)	3.1 (as N <sub>2</sub> O)	43.3
	Chemicals	0	0.77	0	0	0.77
	Electricity	0.063	0.16	0.77	0	1.0
	Fuel	0	0	0.22	0.46	0.68
	Transports	0	9.4	5.7	2.8	17.9
	Infrastructure	0.17	0.19	1.2	0	1.6
	Avoided emissions	0	0	0	-46.8	-46.8
<b>Total</b>		0.23	10.5	48.1	6.4 / -46.8	<b>65.2 / -46.8</b>

We can conclude from Table 4 that:

- Thickening and dewatering emissions are similar between systems 1 and 2. During thickening, they are negligible and during dewatering, emissions are produced by polymers transport.
- More than 70% of the emissions are generated by sludge composting. The other 30% are mainly divided between dewatering (10.5 tons CO<sub>2</sub>eq) and land application (6.4 tons CO<sub>2</sub>eq).
- More than 80% of composting emissions are N<sub>2</sub>O and CH<sub>4</sub> direct emissions. About 12% of the remaining emissions are generated by sludge transport between WWTP and composting site (composting site is supposed to be at a 50km distance).
- Land application emissions are 6.4 tons CO<sub>2</sub>eq, an half is generated by direct emissions. About -47 tons CO<sub>2</sub>eq are avoided. Avoided emissions are due to the non use of mineral fertilizers and to carbon sequestration (respectively -21.8 and -25 tons) as for system 1.

### 3.3 System 3

The third system is responsible of a production of 210 tons CO<sub>2</sub>eq and -146.5 tons CO<sub>2</sub>eq of avoided emissions:

- CO<sub>2</sub> = 198.6 tons CO<sub>2</sub>eq,
- N<sub>2</sub>O = 11.4 tons CO<sub>2</sub>eq.

TABLE 5 GHG emissions of system 3

Tons CO <sub>2</sub> eq		Treatment and disposal steps			
		Thickening	Dewatering	Incineration with household wastes	Total
Emission origin	Direct emissions	0	0	162.9 (as CO <sub>2</sub> ) 11.4 (as N <sub>2</sub> O)	174.3
	Chemicals	0	0.77	1.6	2.4
	Electricity	0.063	0.15	0.73	0.94
	Fuel	0	0	16.0	16.0
	Transports	0	9.4	6.6	16.0
	Infrastructure	0.17	0.19	0.007	0.40
	Avoided emissions	0	0	-146.5	-146.5
	<b>Total</b>	0.23	10.5	199.2 / -146.5	<b>210.0 / -146.5</b>

We can conclude from Table 5 that:

- Thickening and dewatering emissions are similar with systems 1 and 2 (same processes).
- 95% of GHG production is generated during sludge incineration with household wastes.
- About 85% of the emissions generated during incineration are direct emissions. During incineration, sludge and household wastes are mixed. This leads to the emission of fossil CO<sub>2</sub> as household wastes not only contain biogenic carbon in opposition to sludge. Fossil carbon is inevitably incinerated and generated even if it doesn't originate from sludge.
- Avoided emissions in system 3 (-146.5 tons CO<sub>2</sub>eq) are due to the non use of fuel replaced by the heat generated by the incineration with household wastes.

### 3.4 Mass and energy balances

Mass and energy balance for each system are shown in Figure 3.

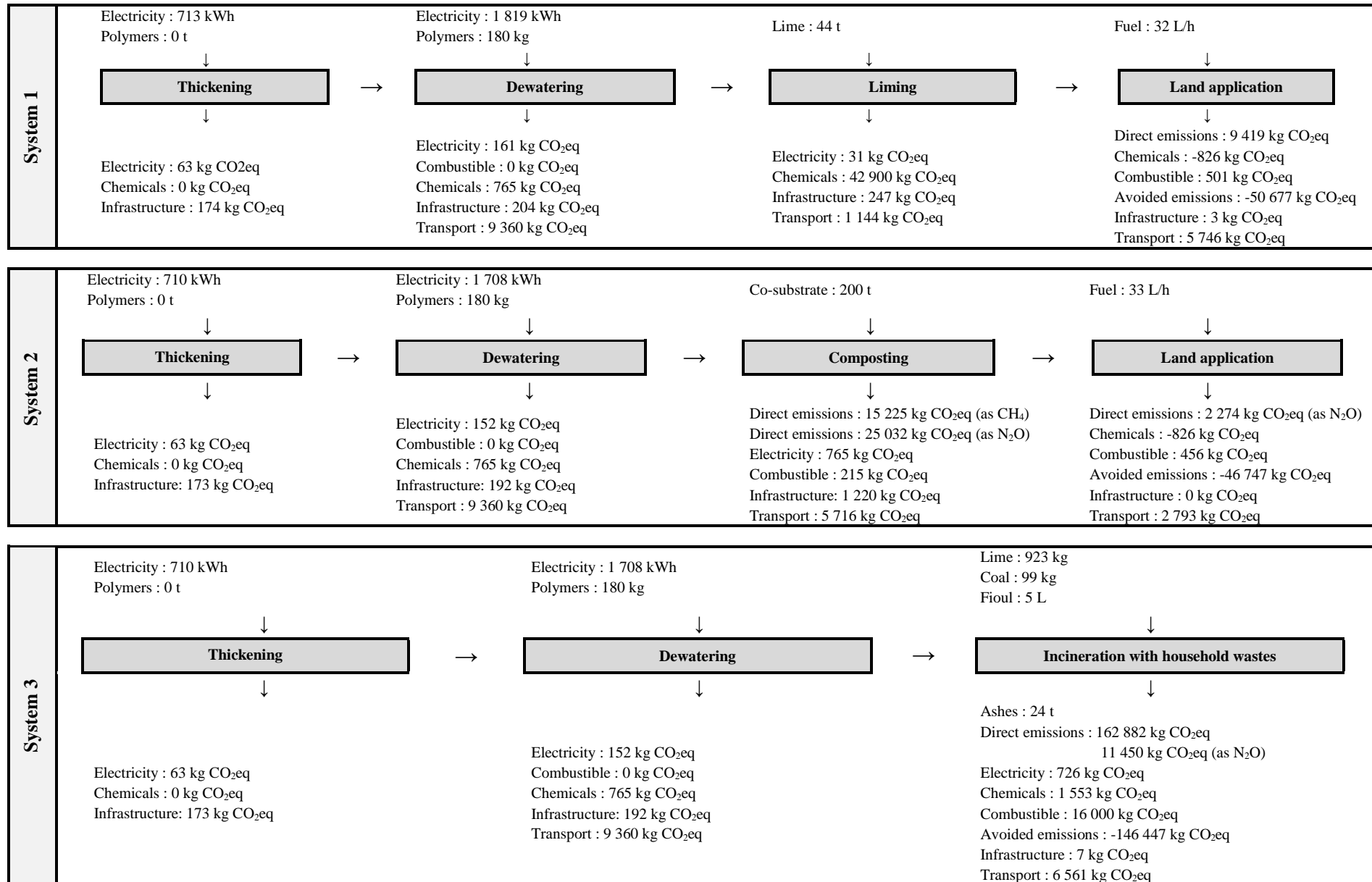


FIGURE 3 Mass and energy balance for the 3 systems

### 3.5 Systems comparison

The three systems were compared regarding the nature of the GHG emitted (Figure 4). Regarding global emissions, the second system is more effective. It produces 65.2 tons CO<sub>2</sub>eq against 71.4 and 210 tons CO<sub>2</sub>eq for respectively the system 1 and the system 3.

Regarding avoided emissions, the second system is the less interesting (-46.8 tons CO<sub>2</sub>eq), but if we sum the global emissions with the avoided ones, it remains the best system. It generates 18.4 tons CO<sub>2</sub>eq against 20.7 tons CO<sub>2</sub>eq for the system 1 and 63.5 tons CO<sub>2</sub>eq for the system 3.

In systems 1 and 3, emissions are mainly CO<sub>2</sub> whereas in system 2, emissions are allocated on a balance between CO<sub>2</sub>, CH<sub>4</sub> and N<sub>2</sub>O.

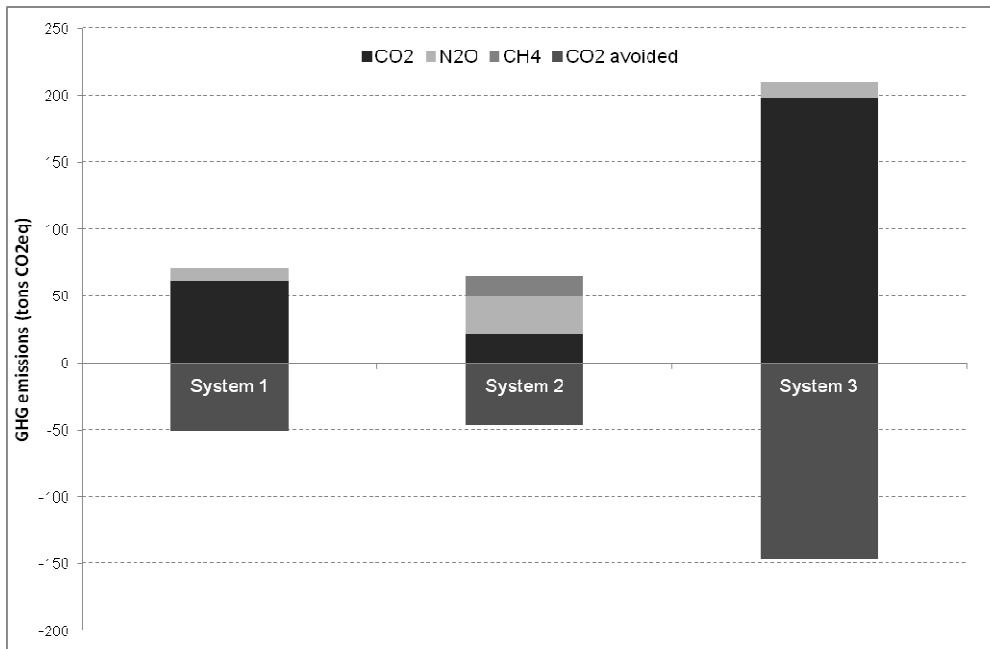


FIGURE 4 GHG emissions comparison in terms of gas nature

Figure 5 compares the three systems regarding each treatment and disposal steps and the origin of emissions.

Emissions during thickening and dewatering are identical because treatments are the same.

Land application GHG emissions vary between system 1 and 2 due to the nature of the sludge. Limed and composted sludges haven't the same agronomic composition and composting decrease dry matter sludge and so the spread quantities. N<sub>2</sub>O emissions generated after spreading and avoided emissions (mineral fertilisers) calculated based on the N content of the sludge are different between the two types of sludge spread. During land application in the first system, 16.5 tons CO<sub>2</sub>eq are generated and -50.7 tons CO<sub>2</sub>eq are avoided. During land application in the second system, 6.4 tons CO<sub>2</sub>eq are generated and -46.8 tons CO<sub>2</sub>eq are avoided.

System 1 produces 2.6 more GHG emissions and only 1.1 more avoided emissions than system 2. The sum between general emissions and avoided emissions leads to -34.2 tons CO<sub>2</sub>eq for the system 1 and -40.4 tons CO<sub>2</sub>eq for the system 2. Sludge composting before land application generates less GHG emissions than sludge liming.

In comparison with sludge spreading in systems 1 and 2, incineration with household wastes appears to be the worst option from an environmental point of view.

The system 2 is the most interesting regarding the Global Warming impact. However, these results should be considered cautiously as data are order of magnitude (average values) and the uncertainty wasn't recorded.

Results are also representative from an environmental point of view and should be compared with economic or social dimensions to give a global approach in waste management. Indeed, a WWTP has to answer to environmental objectives, but it answers first to costs and local pressures.

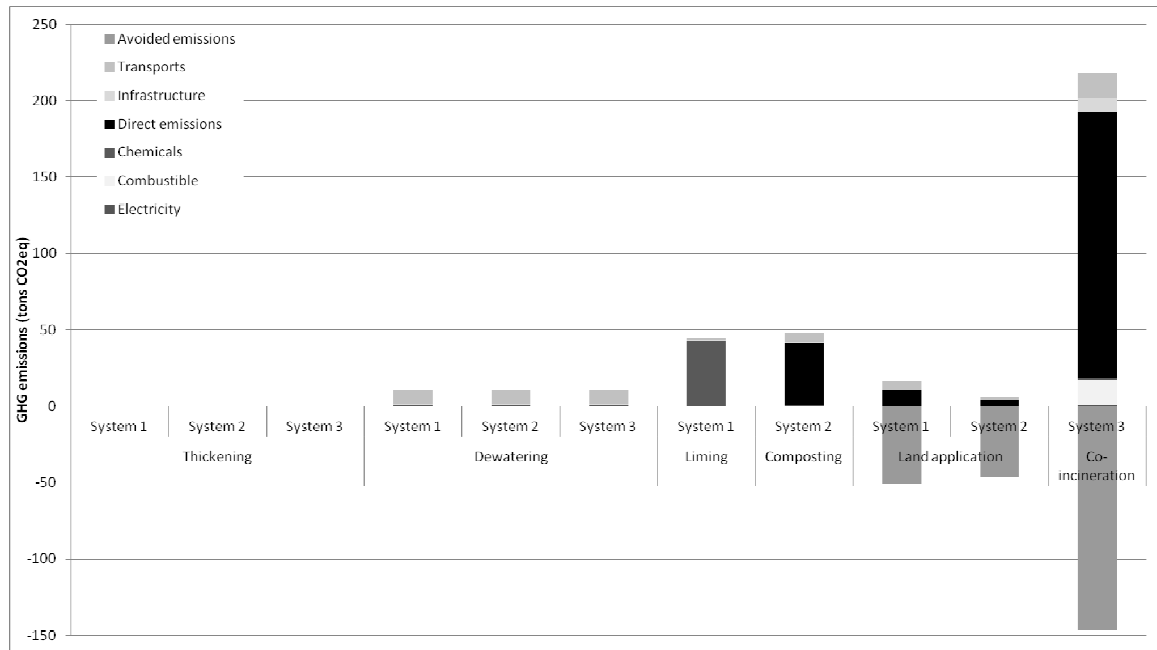


FIGURE 5 GHG emissions comparison for each treatment step and emissions origins

## 4 CONCLUSION

This study was conducted to validate <sup>6</sup>E<sub>s</sub>TABoues tool and to illustrate the type of results that can be obtained between several sludge treatment and disposal routes systems.

Regarding the first results, the system 2 is the most interesting as the 2 others. The results are order of magnitude to compare different systems and to identify the benefits and drawbacks of each system.

However this tool only takes into account greenhouse gases emissions and their impact on Global Warming potential. If we would like to have a complete analysis, we would have to do a Life Cycle Assessment (LCA) completed with economic and social study. We could identify the most respectable environment systems and optimise the worst ones.

## 5 ACKNOWLEDGEMENTS

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