Life Cycle Assessment of different uses of biogas from anaerobic digestion of separately collected biodegradable waste in France

Synthesis

September 2007

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About ADEME :

The French Agency for the Environment and Energy Management (ADEME) is a public agency under the joint supervision of the French Ministries for Ecology, Sustainable Development and Spatial Planning, and for Higher Education and Research. It participates in the implementation of public policies in the fields of the environment, energy and sustainable development. The agency makes its expertise and consultancy skills available to business, local communities, public authorities and the general public and helps them to finance projects in five areas (waste management, soil preservation, energy efficiency and renewable energies, air quality and noise abatement) and to make progress with their sustainable development procedures.

SUMMARY

I. INTRODUCTION

I.1. STUDY AIMS

In the first part of the study, Gaz de France (GdF) and the French Environment Energy Mangement Agency (ADEME) wished to identify the best method to use the biogas from anaerobic digestion of separately collected biodegradable waste (biowaste). Secondly, GdF & ADEME wished to evaluate the strength and weaknesses of the two main different organic recycling: anaerobic digestion (methanisation) and composting.

In this study, two questions were treated:

- **Which is the best valorisation method for biogas produced from the anaerobic digestion of separately collected biodegradable waste :** fuel, heat or electricity? ("Biogas"' question)
- **Which is the best treatment for the separately collected biodegradable waste**: anaerobic digestion (methanisation) or industrial composting? ("Composting" question)

The goal of the study was not to evaluate in detail the environmental impact of industrial composting. The conclusions refer to the variation between these different biological treatment systems but not on the absolute value (which strongly depends on the underlying hypothesis). The results of this study will therefore not allow a comparison between these two biological treatment systems and other methods of treating (incineration, landfill…).

This study is mainly designed for local authority that want to develop a network for the valorisation of the biogas originating from biodegradable waste or who, more generally, look for the best way to treat separately collected biodegradable waste.

I.2. GENERAL METHODOLOGY

The study is based on the life cycle assessment method. The life cycle assessment used for this study consists in quantifying the environmental impacts of all of the activities which are related to the chosen use method. This methodology involves compiling a detailed account of all substances and energy flows removed or emitted from or into the environment at each stage of the life cycle. These flows are then translated into indicators of potential environment impacts. This methodology is based on the internationnal standards ISO14040 and ISO 14044. The life cycle assessment was performed by RDC Environnement.

In order to publish the results and to follow the recommendation of the ISO, the ADEME has ordered a critical review to validate the compliance of the study as well as the data selection and hypotheses used given the study's aims. The members of the critical review committee were the following experts: Yannick Le Guern (LCA expert from BIO Intelligence Service), Penelope Vincent Sweet (France Nature Environnement), Christian Couturier (composting and anaerobic digestion expert from Solagro), Ari Rabl, (Energy and environmental impact expert from the Energy and Process Centre at the Ecole des Mines de Paris).

I.3. DEFINITION OF THE FUNCTIONAL UNIT

To allow a consistent comparison between the different biogas uses and the organic recycling systems, it is necessary to define a common reference in order to express the results for the same output: this common reference is called the functional unit. For the two questions "biogas" and "composting", the following two functional units were chosen:

- **Q. « Biogas »: "*The utilisation of 1 Nm³ of crude biogas (Net Calorific Value 5,7 kWh/Nm³) produced from 8 kg of separately collected biodegradable waste in a methanisation unit".*** The « crude biogas » denomination corresponds to the available biogas at the output before some potential flare and energy utilisation units.
- **Q. « Composting »: *"The utilisation of 8 kg of separately collected biodegradable waste in biogas for different energy uses or in composting"*.** This quantity of biodegradable domestic waste corresponds to the quantity of putrescible waste required for the production of 1 Nm³ of crude biogas.

I.4. CHOICES OF THE IMPACT CATEGORY

The impact categories chosen for this study are (see the annex for definitions):

- Non-renewable primary energy
- Global warming potential (100 years)
- Air acidification
- Eutrophication

The impacts related to the possible presence of metal traces or potentially pathogenic bacteria in compost were not considered in this study. In fact, studies about these impacts have demonstrated that they are negligible when putrescible wastes were separated at the source. Furthermore, the specific impacts of the electronuclear procedure (ionizing radiations, wastes…) were not considered given the current lack in scientific knowledge.

I.5. STUDIED SCENARIOS

The field of the study includes the arrival of the separately collected biodegradable waste at the anaerobic unit as well as the utlisation of the biogas energy and the agricultural use of the digestate from anerobic digestion.

For each biogas utilisation, the environmental impacts of each life cycle stage were considered as well as the impacts that were avoided due to the substitution of the use of non-renewable energy ("conventional" procedures). The following table shows the main underlying hypotheses for each scenario and the substituted "conventional" procedures.

To answer the question about biological treatments, we also present the impact of the alternative treatment (closed-off composting) of separately collected biodegradable waste required for the production of 1 Nm³ of crude biogas (**8,3 kg**). The modelling of the direct composting of the biodegradable waste was realised taking into account the followings aspects:

- The emissions during industrial closed-off composting, with drainage and airing systems (biological filter)
- The emissions during the spreading of the compost.
- The avoided emissions in case of the agricultural use of the compost for vegetable farming, market gardening.

<table>
<tr><th rowspan="2"></th><th rowspan="2">Procedure</th><th colspan="2">Utilisation method</th><th colspan="2">Substituted systems</th></tr>
<tr><th>Nm^3 of used biogas[1]</th><th>Production of raw biogas</th><th>Avoided function</th><th>Avoided pocess</th></tr>
<tr><td rowspan="8">*Functional Unit: Valorisation of 1 Nm^3 of crude biogas*</td><td>**Heat (fuel oil)**</td><td rowspan="2">Combustion of **0,82 Nm^3 of crude biogas** in a boiler of 2 to 20 MWth</td><td rowspan="2">▪ Digestion of **8,3 kg of biodegradable waste** with digestate composting and the utilisation of **3 kg of metha-compost.**
▪ Combustion of **0,08 Nm^3 of crude biogas** in a boiler in order to satisfy the heating requirements of the site
▪ Consumption **of 0,83 kWh taken from the network**
▪ Combustion of **0,1 Nm^3 of crude biogas at the flare**</td><td rowspan="2">Generation of **3,9 kWh_{th} /** (in case of heat utilisation of 100%)</td><td>Production and combustion of **0,45 litres of fuel oil** in an industrial boiler of 1 MWth.</td></tr>
<tr><td>**Heat (natural gas)**</td><td>Production and combustion of **0,45 Nm^3 of natural gas** in an industrial boiler with the power of > 100 kWth.</td></tr>
<tr><td>**Electricity**</td><td>Combustion of **0,46 Nm^3 of crude biogas** in a generator of 650 kW</td><td rowspan="3">▪ Digestion of **8,3 kg of biodegradable waste** with digestate composting and the utilisation of **3 kg of metha-compost**
▪ Combustion of **0,44Nm^3 of crude biogas** in a boiler in order to satisfy the heating and electricity requirements of the site
▪ Combustion of **0,1 Nm^3 of crude biogas at the flare**</td><td>Generation of **0,85 kWh_e**</td><td>Generation of **0,85 kWh_e** according to the average model of electricity production in France.</td></tr>
<tr><td>**Cogeneration (fuel oil)**</td><td rowspan="2">Combustion of **0,46 Nm^3 of crude biogas** in a cogeneration unit of 2 to 20 MWth</td><td rowspan="2">Generation of :
▪ **0,85 kWh_e**
▪ **1,9 kWh_{th}**
(in case of heat utilisation of 100%)</td><td>Generation of **0,85 kWh_e** according to the average model of the electricity production in France.
Production and combustion of **0,22 litres of fuel oil** in an industrial boiler of 1 MWth.</td></tr>
<tr><td>**Cogeneration (natural gas)**</td><td>Generation of **0,85 kWh_e** according to the average model of electricity production in France.
Production and combustion of **0,21 Nm^3 of natural gas** in an industrial boiler with the power of > 100 kWth.</td></tr>
<tr><td>**Fuel (diesel)**</td><td rowspan="3">Combustion of **0,47 Nm^3 of biogas as fuel** in a bus, car or waste trucks
This biogas as fuel is produced from **0,82 Nm^3 of crude biogas** with 57% of methane</td><td rowspan="3">▪ Digestion de **8,3 kg of biodegradable waste** with digestate composting and the utlisation of **3 kg of metha-compost**
▪ Combustion of **0,08 Nm^3 of crude biogas** in a boiler in order to satisfy the heating requirements of the site
▪ Consumption **of 0,99 kWh_e taken from the network**
▪ Combustion of **0,1 Nm^3 of crude biogas at the flare**</td><td rowspan="3">Journey of :
▪ **0,64 km** by bus
▪ **6,8 km** by car
▪ **0,40 km** by waste truck</td><td>Production and consumption of diesel fuel :
▪ **0,38 litre** for a bus
▪ **0,39 litre** for a car
▪ **0,34 litre** for a waste truck</td></tr>
<tr><td>**Fuel (petrol)**</td><td>Production and consumption of petrol:
▪ **0,54 litre** for a car</td></tr>
<tr><td>**Fuel (natural gas for vehicles)**</td><td>Production and consumption of natural gas for vehicles
▪ **0,48 NNm^3**</td></tr>
</table>

[1] *« Nm^3 of utilised biogas »: calculated according to the following formula: 1 m^3 of crude biogas at the output of the digestion tank minus the auto-consumed part and the part which is burnt in the flare*

II. RESULTS AND CONCLUSIONS

II.1. What is the best biogas utilisation?

The following table shows the results for the four indicators of potential environmental impacts that were used for this study for each utilisation method.

The negative figures (in light grey) show that the emissions from the biogas production are lower than those emissions avoided due to the combustion of non-renewable energies.

The positive figures [1] *(in dark grey)* show that the emissions from the biogas production are higher than those emissions avoided due to the combustion of non-renewable energies.

The figures in **bold** point out the best method for each indicator.

Functional unit : Utilisation of 1 Nm³ of crude biogas (Net Calorificc Value 5,7 kWh/Nm³)

Biogas use (substituted procedure)	Primary energy non-renewable MJ	Global warming potential (100 years) in g eq CO2	Air acidification in g eq SO2	Eutrophication in g eq PO42-
Heat (Fuel oil)	-13	-1 390	1,5	0,59
Heat (Natural gas)	-8,6	-1 141	4,0	0,74
Electricity	-9,8	-327	3,8	0,76
Cogeneration (Fuel oil)	**-20**	-920	3,2	0,72
Cogeneration (Natural gas)	-18	-800	4,4	0,80
Carburant (Bus with diesel fuel)	-7,0	-1 176	**-4,7**	0,11
Carburant (Bus with natural gas)	-7,8	-1 297	3,0	0,70
Carburant (Waste truck with diesel)	-5,1	-1 020	**-4,9**	**0,10**
Carburant (Waste truck with natural gas)	-7,8	-1 299	3,0	0,70
Carburant (Car with diesel)	-7,4	-1 241	1,2	0,54
Carburant (Car with petrol)	-13	**-1 566**	0,88	0,56
Carburant (Car with natural gas)	-7,8	-1 336	3,0	0,70

Conclusion 1 : **The environmental performance of the utilisation of biogas is moderate when compared to the use of non-renewable energy.**

For both different energy uses (heat and fuel), the utilisation of biogas shows an advantage in terms of the consumption of non-renewable primary energy and the global warming potential (for 100 years). Including global warming gas emissions of the separate waste collection into the calculation does not call into question the advantage of the different utilisation methods for this indicator. The observed trends for the primary energy performance are similar to those for the global warming potential indicator with better results for the cogeneration procedure because of the inclusion in the calculation of avoided uranium for electricity generation.

The utilisation of biogas shows an advantage in terms of the air acidification only if it substitutes diesel fuel for a bus or a waste truck. The use of biogas avoids the emission of sulphur compounds which are contained in diesel fuel. The utilisation of biogas fuel in a bus or a waste truck emits less Nitrogen oxides than the utilisation of diesel fuel (which is not the case for lighter vehicles).

The utilisation of biogas energy does not provide an advantage in terms of eutrophication whatever the biogas utilisation. The energy recovery which brings about the lowest impacts are the use of biogas as fuel for busses and waste trucks when susbtituting the use of diesel fuel.

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[1] *The positive figures show that the biogas production impacts are higher than the environmental benefits of its utilisation. This does however not mean that* ***this utilisation of organic waste does generally not make sense as this study does not take into account avoided treatment such as incineration or landfill.***

Conclusion 2 : The different biogas uses such as fuel for busses or waste trucks which substitutes diesel fuel are the more interesting in relation to the 4 indicators (global warming potential, air acidification, eutrophication and consumption of primary energy)

Overall, for the impacts on global warming potential, air acidification and eutrophication, the biogas different uses as fuel appears as more positive than in the form of cogeneration and electricity. This tendency is less obvious for the impacts on air acidification and eutrophication if the substituted fuel is natural gas.

The biogas utilisation as fuel for a bus or a waste truck which substitutes diesel fuel is especially interesting for the “air acidification” and “eutrophication” indicators.

Conclusion 3 : The use of biogas in cogeneration is especially interesting for the consumption of primary non-renewable energy.

Regarding the impact primary non-renewable energy, the cogeneration is the most preferable use as it allows to reach a high output due to the production of electricity and heat.

Regarding the other impacts, the cogeneration has a worse environmental performance than the use of biogas for heat production substitued at fuel oil. The avoided impacts due to combined heat and electricity production are lower than the impacts avoided by the heat production only [2]. This assumes that 100% of the produced heat are utilised. If the heat demand of an external customer are the same for the both utilisation procedures (heat production and cogeneration), the use of biogas in a cogeneration is more interesting in terms of the global warming gas emissions due to the avoided production of electricity.

Conclusion 4 : Electricity production is the worst procedure for the “global warming potential” impact.

The avoided impacts depend mainly on the nuclear electricity generation which emits relatively few global warming gases. This production method has however some specific impacts not included in this study, especially the production of radioactive waste. If the biogas can be used to substitute electricity production from a natural gas power plant, this utilisation method becomes very interesting in terms of its global warming contribution. In this case, the biogas utilisation method based on electricity production is better than its utilisation as fuel in waste trucks with the substitution of diesel.

For the other impact categories, the use of biogas in electricity generation allows to avoid energy consumption but with a lower output than the heat production utilisation (with fuel oil substitution), cogeneration, and the fuel use (substituting petrol in a car).

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[2] *The impacts avoided due to the electricity production mainly depend on the nuclear based electricity production, which emit relatively low amounts of global warming gases and acidifying gases compared to the emissions of a fuel oil boiler.*

II.2. WHAT IS THE BEST TREATMENT OF THE BIODEGRABLE WASTE ?

The following table shows the best treatment method for biodegradable waste for each indicator chosen for this study. The number of (✓**)** signs represents the relative importance of the results.

	Anaerobic digestion with agricultural & energy utilisation	**Composting with agricultural utilisation**
Primary energy	✓✓	
Global warming potential	✓✓	
Eutrophication		✓ except for anaerobic digeston with biogas utilisation as fuel for busses and waste trucks while substituting diesel fuel
Air acidification	Depends on the biogas valorisation	

The utilisation of biodegradable waste as biogas is potentially more interesting than composting in terms of the global warming potential and primary energy balance, whatever the energy utilisation method used.

This is related to the fact that the avoided emissions of global warming gases and the avoided consumption of primary energy due to the substitution of the classic energy generation procedures are higher for the utilisation of biogas method than for composting.

Regarding the eutrophication category, biogas production has a higher impact than the composting method because of the large amounts of liquid discharge during the anaerobic process except for its utilisation as fuel with diesel oil substitution in busses or waste trucks.

In regard to the air acidification category, anaerobic digestion is preferable to the direct composting of biodegradable waste for the utilisation method of biogas as fuel with diesel or petrol substitution and for biogas utilisation for heat production with fuel oil substitution. The other biogas utilisation (electricity, or the substitution of natural gas or natural gas for vehicles) bring about the same amount of acid emissions (for the utilisation of biogas as fuel substituting natural gas for vehicles) or slightly higher than the direct composting of the biodegradable waste. The ranking of some procedures is sensitive to the rate of the air emissions of ammoniac from the composting pad.

II.3. ELEMENTS FOR DECISION MAKING

In order to choose the utilisation method for biogas produced from separately collected domestic biowaste the following factors should be taken into account:

1. To favour the utilisation method offering the best utilisation rate

The percentage of biogas burned at the flare is the biogas percentage which not used and by deducting it, one obtains the biogas utilisation rate. These rates vary highly according to the production site: adequacy of the capacity of the anaerobic digestion in relation to the energy equipment (engines, boilers, number of vehicles), variations in energy demand (utilisation of the heating in summer, utilisation of the vehicles on the week-end,…), regulation of the biogas production (gasometer, …).

The analysis of the biogas utilisation has to take into account the local context in order to evaluate the potential opportunities for the energy utilisation. If the demand for heat is variable or punctual, the cogeneration should also be considered. If the demand for heat is strong, stable and constant (for example an industrial heat consumer close by), a thermal utilisation of the biogas would bring about most of the potential benefits.

In any case it is of course interesting to try and reduce the amount of biogas burned at flare.

2. To limit the amount of wastewater during the anaerobic digestion

This parameter has an important influence on the water emissions (N and P) which contribute to the eutrophication.

3. To valorise the compost

For the choice of a treatment method of separately collected biodegradable waste, it is necessary to pay attention to the effective utilisation of the compost. This part is actually not negligible for the global balance of all the selected impacts.

II.4. CRUCIAL POINTS TO EXPAND ON

Some key points which could influence the previous conclusions would have to be studied in more detail:

II.4.1. Analyse of NH_3, CH_4 and N_2O air emissions during the composting stage of biodegradable waste and the digestate

To answer the « composting » question in more detail, it could be useful to produce comparative carbon and azote balances of one tonne of biodegrable waste used for one unit of anaerobic digestion or one pad of compost. **It should be noted that currently there is a certain lack of data to produce these balances.**
The realisation of the sensitivity analysis has however underlined the following points:

- The anaerobic digestion with energy recovery is preferable to direct composting regarding the impact category "increase in global warming potential", even when considering that the methane and N_2O emissions during the digestate composting stage was one and a half times higher than the same emissions during the direct composting of domestic biodegradable waste.
- The ranking of anaerobic digestion compared to direct composting varies according to the considered method of energy utilisation and with the difference in the NH_3 emissions between the composting of the digestate and the direct composting of the domestic biodegradable waste.

II.4.2. Considerations on the mixed electricity hypotheses

The mixed electricity hypotheses strongly influence the conclusions for the category « The rise in global warming potential » for the electric and cogeneration procedures because of the non-consideration of the specific impacts of the nuclear electricity production and because of the particularly low global warming gas emissions from the average French mix.

It is also important to clearly define the procedure of electricity generation which would be substituted by the biogas electricity generation in case it would be fed in into a network.

It should be remembered that if the biogas could be used for electricity generation substituting a natural gas power plant, this utilisation method becomes a very good solution in relation to the impact category "global warming potential" for the next 100 years.

II.4.3. Analysis of available techniques for the limitation of methane emissions during the purification of crude biogas

The forecasted losses for the existing installations are equal to 2%[3]. With new technologies, it could be possible to reduce these losses to under 0.04 %. However given the necessary time to acquire these technologies, a loss of 1% is conceivable in the mid-term.

Regarding the impact category "global potentials", if the losses of biogas as fuel at the purification unit are effectively limited to 0.04%, the difference between the biogas as fuel while substituting natural gas for vehicles in busses, waste trucks or cars and the heat production utilisation procedure substituting fuel oil becomes negligible.

Whatever might be the losses of biogas as fuel in the purification unit, the heat production utilisation procedure substituting fuel oil is preferable to using biogas as fuel for cars or buses substituting diesel.

II.4.4. Measurements of the emissions during the cumbustion of the biogas

The emissions due to the biogas combustion in boilers or generators correspond to the maximum emission values of the publication from 10 December 2003 and to the results of the measurement performed by the INERIS[4] in 2002. These emissions are probably overestimated which penalises the environmental balance of the crude biogas utilisation. **New measurements would allow using more accurate values for the calculation.**

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[3] *In a report published in 2003 by the Svenskt Gastekniskt Center : " Utvärdering av uppgraderingstekniker för biogas" some measurements performed on purification units of biogas in Sweden have shown that the losses of biogas as fuel could have reached 10% in the past.*

[4] *INERIS (2002) « Caractérisation des biogaz, bibliographie et mesures sur sites », 82p.*

III. GLOSSARY

III.1.1. Definition :

Cunsumption of non renewable primary energy

Primary energy is raw energy available in nature. The main non-renewable primary energies are: oil, coal, natural gas, and nuclear energy.

Air acidification

Air acidification consists in the accumulation of acidifying substances (e.g. sulphuric acid, hydrochloric acid) in the water particles in suspension in the atmosphere. Deposited onto the ground by rains, acidifying pollutants have a wide variety of impacts on soil, groundwater, surface waters, biological organisms, ecosystems and materials (buildings).

Global Warming Potential

Global warming refers to the increase in the average temperature of the Earth's surface, due to an increase in the global warming potential, caused by anthropogenic emissions of global warming gases (carbon dioxide, methane, nitrous oxide, fluorocarbons (e.g. CFCs and HCFCs), and others).

Eutrophication

Eutrophication is a process whereby water bodies, such as lakes or rivers, receive excess chemical nutrients – typically compounds containing nitrogen or phosphorus – that stimulate excessive plant growth (e.g. algae). Nutrients can come from many sources, such as fertilisers applied to agricultural fields and golf courses, deposition of nitrogen from the atmosphere, erosion of soil containing nutrients, and sewage treatment plant discharges.