Study on Biogas as vehicle fuel in Europe

Final report – LCA section

June 2006

ADEME – Gaz de France

BIOVE project - LCA

1. Objective and scope of the study
2. Key data and assumptions
3. Results
4. Conclusions

Objective of the study

Answering the questions :

Q. Biogas : *« From an environmental point of view, which is the best* ***valorisation method for biogas*** *produced from selectively collected putrescible waste : vehicle fuel, heat, electricity or combined heat and power ?"*

Q. Compost : *" From an environmental point of view, which is the best* ***treatment for selectively collected putrescible waste*** *(methanisation or compost) ? "*

Objective of the study

Functional units :

Q. Biogas : ***"Valorisation of 1 Nm³ (PCI 5,7/kWh/Nm³) crude biogas produced from a biomethanisation unit for selectively collected PW".***

Q. Compost : ***"Valorisation of 8 kg selectively collected PW in a biomethanisation unit or in a compost unit "*** *(corresponding to the production of 1m^3)*

Data and assumptions

Vehicle emissions

•Data (g/km)	•Bus (1)			•DRCV (2)			•Cars (3)		
	•Diesel	•Diesel •(DPF)	•NGV/Biogas	•Diesel	•Diesel •(DPF)	•NGV/Biogas	•Gas	•Diesel •(DPF)	•NGV/Biogas
•CO2	•1530		•1529	•2193		•2479.459459	•184	•151	•148
•CO	•2,38	•0,05	•0,03	•9,3	•7,3	•7,2	•0,58	•0,16	•0,39
•NMVOC	•1,04	•0,02	•-	•2,2	•1,4	•0,05	•0,039	•0,026	•-
•CH4	•-	•-	•1,14	•-	•0	•4,9	•-	•-	•0,094
•NOx	•19,5	•18,9	•4,5	•31,4	•32,0	•6,2	•0,02	•0,2	•0,056
•SOx	•0,05	•0,05	•-	•0,07	•0,07	•-	•0,004	•0,003	•-
•Particles	•0,18	•0,004	•0,01	•1,3	•0,2	•0,03	•-	•0,011	•-
•Consumption •(l or Nm³/100 km)	•60		•74	•86		•120	•7,8	•5,7	•6,9

Source : (1) : [S.3, ADEME, 2005]

(2) : [S. 4, ADEME, 2003]

(3) : Data were given by Gaz de France and come from databases of ADEME and the Vehicle Certification Agency

Data and assumptions

Supply sources

Crude Oil

- North Sea : 31%
- Middle East : 26%
- Nigeria : 15%
- Algeria et Libya: 7%
- Russia : 21%

Natural Gas

- Norway : 34%
- The Netherlands: 24%
- Former USSR : 26%
- GNL : 16%

Biogas

Selectively collected PW

Data and assumptions - Diesel

Crude oil extraction

Supply sources	CO_2 [g/kWh]	CH_4 [g/kWh]	NOx [g/kWh]	SOx [g/kWh]
North Sea	1,46	0,003	0,013	0,006
Africa (Nigeria)	33,54	1,03	0,15	0,003
Africa (Algéria and Libya)	20,04	0,19	0,11	0,03
Russie	35,37	0,25	0,22	0,99
Middle East On-shore	7,5	0,065	0,06	0,016

Source : Ecoinvent v1.2

Oil refinement

Fuel	Efficiency	CO2	NOx	HC	CO	SO2	CH4	Part
Gas	92,1%	23,38	0,039	0,0025	0,0040	0,22	0,0014	0,016
Diesel	96,3%	13,31	0,016	0,0011	0,000	0,10	0,00036	0,0076

Source : IFP, 2002

Data and assumptions – Natural gas

Transport of natural gas

Supply sources	Average distance (km)	Energy consumption	Direct losses of methane	CH_4 [g/kWh]	CO_2 [g/kWh]	NOx [g/kWh]
Norway	1000	2,50 %	0,16 %	0,09	5,35	0,011
The Netherlands	300	0,64 %	0,05 %	0,034	1,3	0,003
Former USSR (Sibéria)	7000	21,5 %	Range between 1 and 3,6%	1,45	44,36	0,009
Former USSR (Caspian sea)	5000[1]	15,4 %	Range between 0,7 and 2,6%	1,02	31,77	0,07

Data and assumptions – Natural gas

Liquefied Natural Gas

	Energy consumption	CO_2 [g/kWh]	CH_4 [g/kWh]	CO_2 – équivalent [g/kWh]
NG Extraction and treatment	1,3 %	2,74	0,47	13,55
Liquefaction	13 %	27,3	0,06	28,68
Transport	10% (54% NG et 46% Crude oil)	26,3	0,0006	26,3

Data and assumptions - Biogas

Biomethanisation of putrescible waste

	Min	Max	Average data used in our model
Mass balance			
Performance of crude biogas production (m³/t)	100	140	120
Performance of compost production (kg/t $_{de\ PW}$)	300	450	375
Amount of wastewater (m³/t)	0	0,186	0,0093 (treated in WWTP)
Energy balance			
Auto-consommation of biogas Valorisation as heat and fuel	5	9	8
Auto-consommation of biogas Valorisation as electricity and CHP	38	50	44
Biogas losses	0	0,05%	0,025%
Biogazs burnt in flare stacks	2	30	10

Data and assumptions – Biogas

Cleaning of biogas

	Min	Max	Reference value used in our model
Mass balance			
Water consumption (m^3/m^3 of biogaz outgoing)	0,001	0,17	0,001
Energy balance			
Auto-consommation (in % of biogaz outgoing)	0	0	0
Biogas losses (in % of biogaz outgoing)	0,04	4	2
Electric consumption ($kWh_{élec}/Nm^3$ of biogas outgoing)	0,14	0,69	0,42

NB : For biogas losses, 40 to 50 % of CH_4 is degraded to CO_2 in the biofilter.

Data and assumptions – Biogas

Emissions from biogas combustion

	Efficiency	NOx	SOx	CO	COVNM
Furnace	85 %	0,23	0,09	0,25	0,05
CHP	45/37 %[1]	0,53	0,09	1,22	0,05
Electic generator	37 %	0,32	0,09	0,29	0,16

[1] Thermal/electric

Source :

- Furnace : ELV from the circulaire (10-12-03)
- Electric generator : measure on sites in 2002 by INERIS
- CHP : ELV from the circulaire (10-12-03)
- SOx : ELV from the directive 2000/76/CE on incineration

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Data and assumptions – Biogas

Alternative treatments of PW

				Reference value of the model	
Mass balance				**direct composting of biodegradable waste**	**Composting of metha-compost**
Performance of compost production (kg/t $_{of\ PW}$)	The decomposition rates during the methanisation phase and the thermopile phase of the composting are considered to be similar			**375**	
	Inventory of LCA knowledge	**EPER study**	**AOO**		
Energy balance					
Diesel (litres/t $_{of\ PW}$)	2 to 4	-	-	**3**	
Electricity (kWhe/t $_{of\ PW}$)	30 to 100	-	32	**60** [2]	**Included in the overall electricity consumption of the biogas plant (99,9kWhe/t$_{of\ PW}$)**
Air emissions (after biofilter)					
NH_3 (g/t $_{of\ PW}$)	159	777	200	**159**	
CH_4 (g/t $_{of\ PW}$)	Between 200 and 5300	3160	2400	**2400**	**0**
N_2O (g/t $_{of\ PW}$)	13,6[1]	negligible	96	**13,6**	

Data and assumptions – Biogas

Alternative treatments of PW

- Compost valorisation : RDC study, 2005
  - ✓ Environmental impacts (manure spreading)
    - ➢ N_2O : 42 g/t
    - ➢ CO_2 : 162 g/t
    - ➢ NH_3 : 227 g/t
    - ➢ Diesel : 0,65 kg/t
  - ✓ Environmental benefits
    - ➢ Carbon storage : 22 kg CO_2/t
    - ➢ Avoided production of fertilisers (≠ for ≠ processes)

Data and assumptions – Biogas

Substituted production (avoided emissions)

- Heat (E_{therm})

	Efficiency	CO_2	CH_4	NOx	SOx	CO	Part
Natural gas boiler	90 %	202	0,008	0,06	0,002	0,008	0,0007
Oil boiler	90 %	266	0,004	0,18	0,17	0,014	0,0004

- Electricity (E_{elec})

	CO_2	NOx	SOx	CO	CH_4	COVNM
Average electric mix in France	92,4	0,28	0,38	0,06	0,11	0,022
Combined gas and steam turbines system (NG)	455,9	0,56	0,13	0,18	1,14	0,093

Source :

- Boiler : DB Ecoinvent for combustion + LCA model
- Electricity : DB Ecoinvent

Results

- ✓ Summary of studied scenarios
- ✓ Greenhouse gas emissions
- ✓ Eutrophication
- ✓ Energy consumption
- ✓ Acidification increase

+ sensibility analysis

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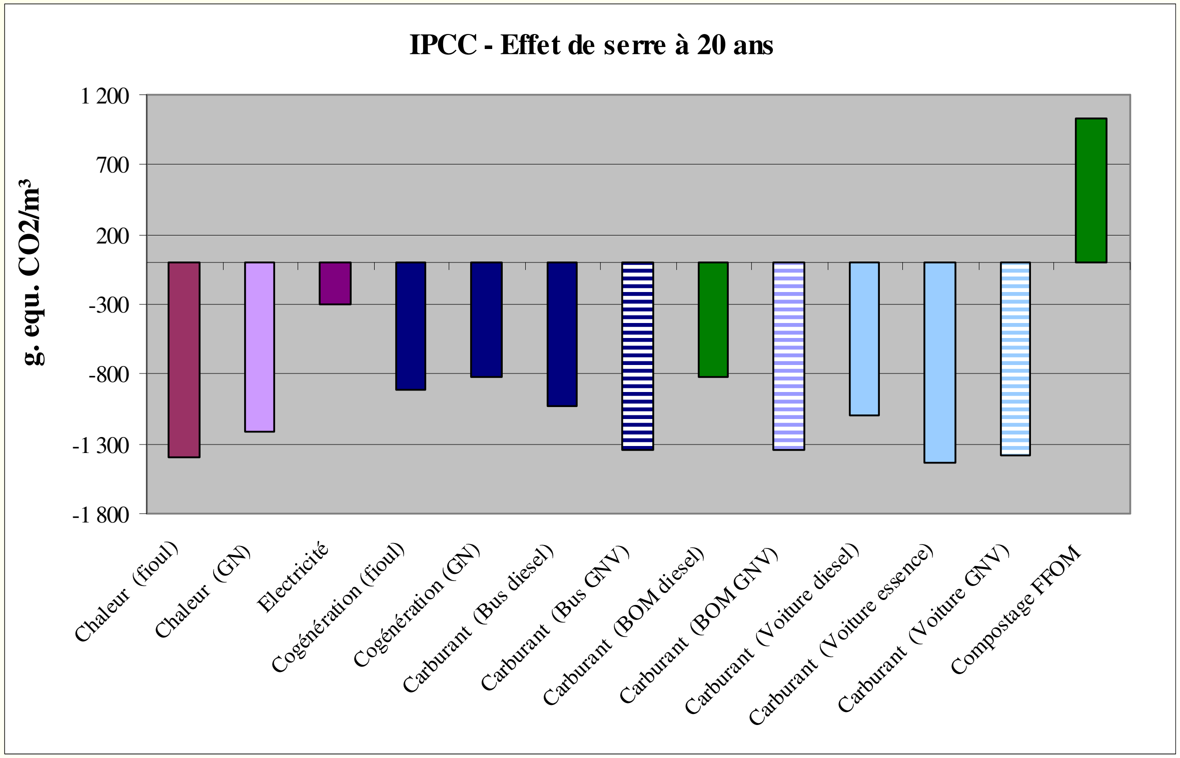
Summary of scenarios

	Procedure	Utilisation method		Substituted systems	
		Nm^3 of used biogas[1]	Production of raw biogas	Avoided function	Avoided pocess
Functional Unit: Valorisation of 1 Nm^3 of crude biogas	**Heat (fuel oil)**	Combustion of **0,82 Nm^3 of crude biogas** in a boiler of 2 to 20 MWth	▪ 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**	Generation of **3,9 kWh_{th}** / (in case of heat utilisation of 100%)	Production and combustion of **0,45 litres of fuel oil** in an industrial boiler of 1 MWth.
	Heat (natural gas)				Production and combustion of **0,45 Nm^3 of natural gas** in an industrial boiler with the power of > 100 kWth.
	Electricity	Combustion of **0,46 Nm^3 of crude biogas** in a generator of 650 kW	▪ 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**	Generation of **0,85 kWh_e**	Generation of **0,85 kWh_e** according to the average model of electricity production in France.
	Cogeneration (fuel oil)	Combustion of **0,46 Nm^3 of crude biogas** in a cogeneration unit of 2 to 20 MWth		Generation of : ▪ **0,85 kWh_e** ▪ **1,9 kWh_{th}** (in case of heat utilisation of 100%)	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.
	Cogeneration (natural gas)				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.
	Fuel (diesel)	Combustion of **0,47 Nm^3 of biogas as <u>fuel</u>** 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	▪ 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**	Journey of : ▪ **0,64 km** by bus ▪ **6,8 km** by car ▪ **0,40 km** by waste truck	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
	Fuel (petrol)				Production and consumption of petrol: ▪ **0,54 litre** for a car
	Fuel (natural gas for vehicles)				Production and consumption of natural gas for vehicles ▪ **0,48 NNm^3**

Results : GHG emissions



For the impact category : **« Increase of greenhouse effect, 100 years »,** it is always beneficial to valorise the biogas produced from PW

Biomethanisation is preferable to composting for all biogas valorisation methods

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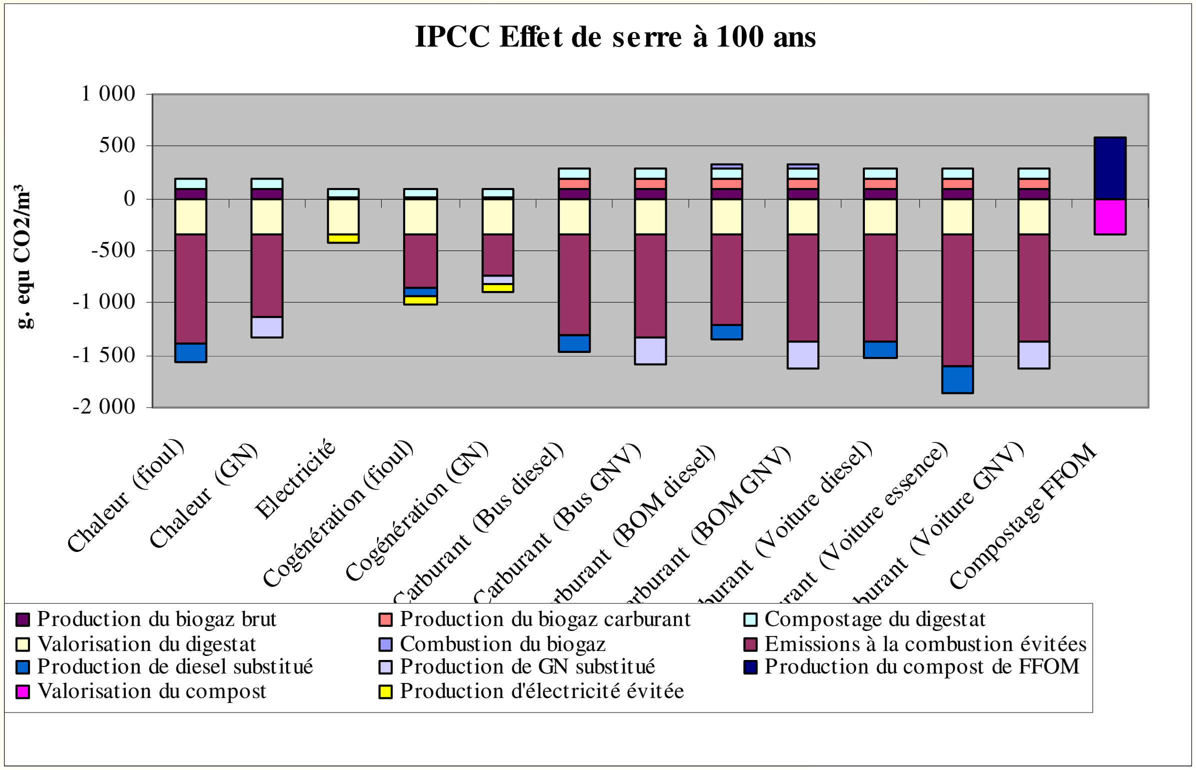
Results : GHG emissions



Emissions

Avoided emissions

Importance of GHG emissions avoided by **agronomical valorisation of compost** and through **non combustion of fossil energies**

Results : GHG emissions

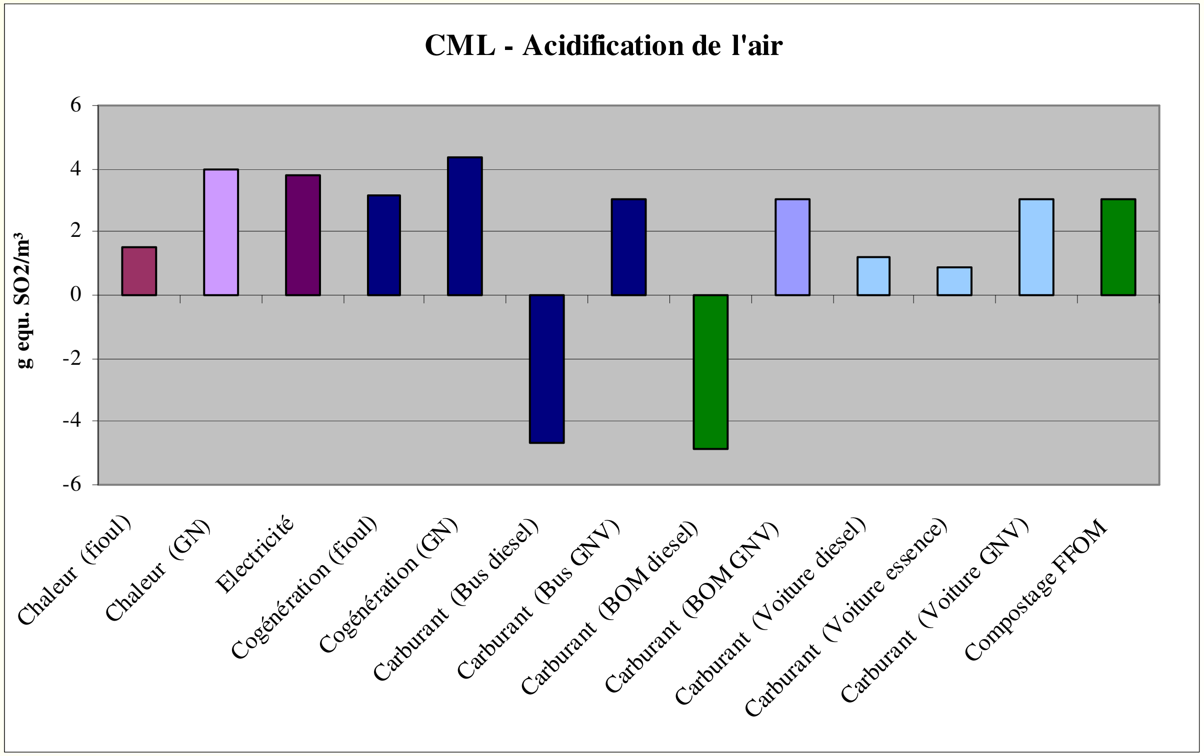
Main emissions (common to all valorisation methods) :

- CH_4 linked to the combustion of biogas in flare stacks
- N_2O emitted during biomethanisation
- Avoided emissions of CO_2 and N_2O during valorisation of the compost

Main emissions (variable according to valorisation method) :

- CH_4 during losses of biogas fuel
- GHG emissions according to type and amounts of fossil fuels substituted

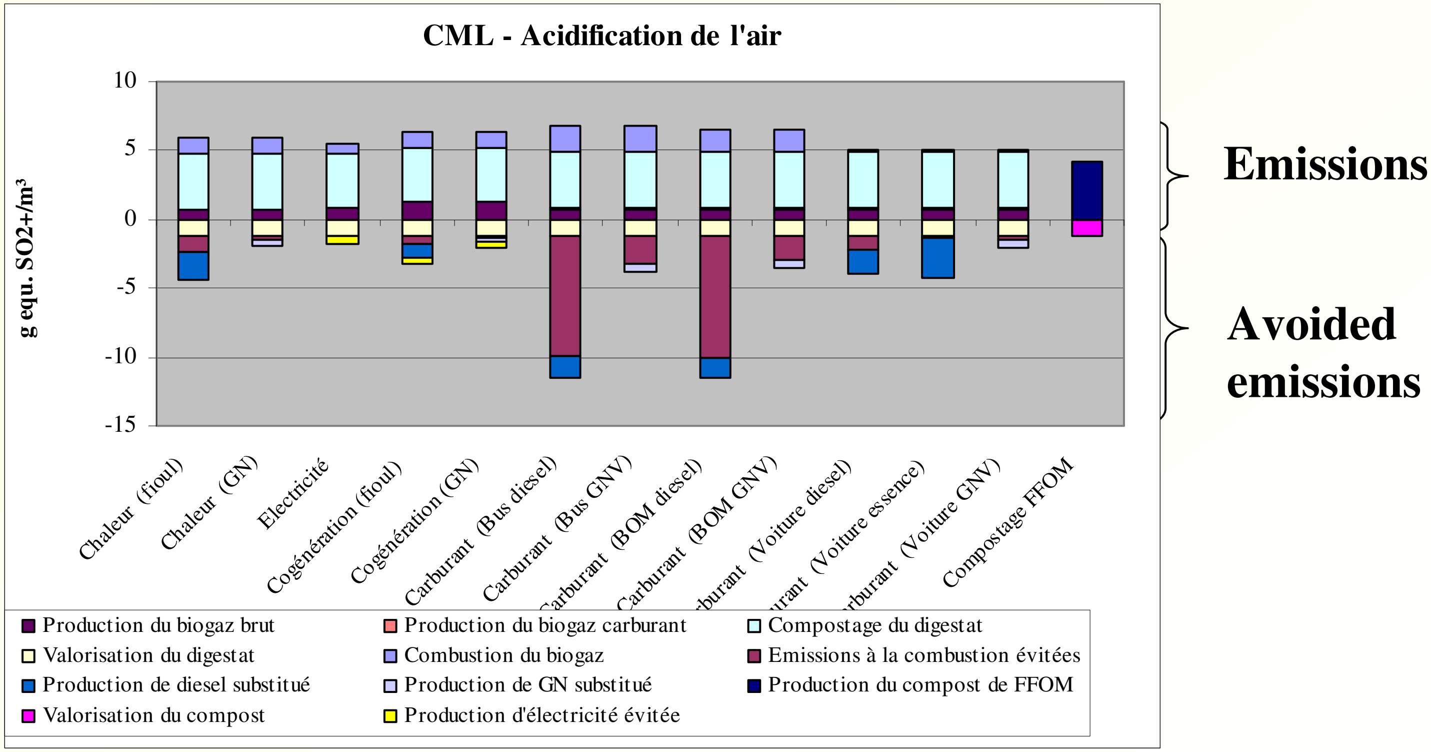
Results : Acidification



Methods of biogas valorisation in substitution for diesel in buses and waste collection vehicle (WCV) are the only ones for which the avoided emissions are higher.

Biomethanisation is preferable to composting only in case of diesel or gasoil substitution (except for CHP)

Results : Acidification



Significant emissions of

- **NH_3 during composting of the digestate and spreading**
- **NOx during combustion of the biogas and fossil fuels**

Results : Acid emissions

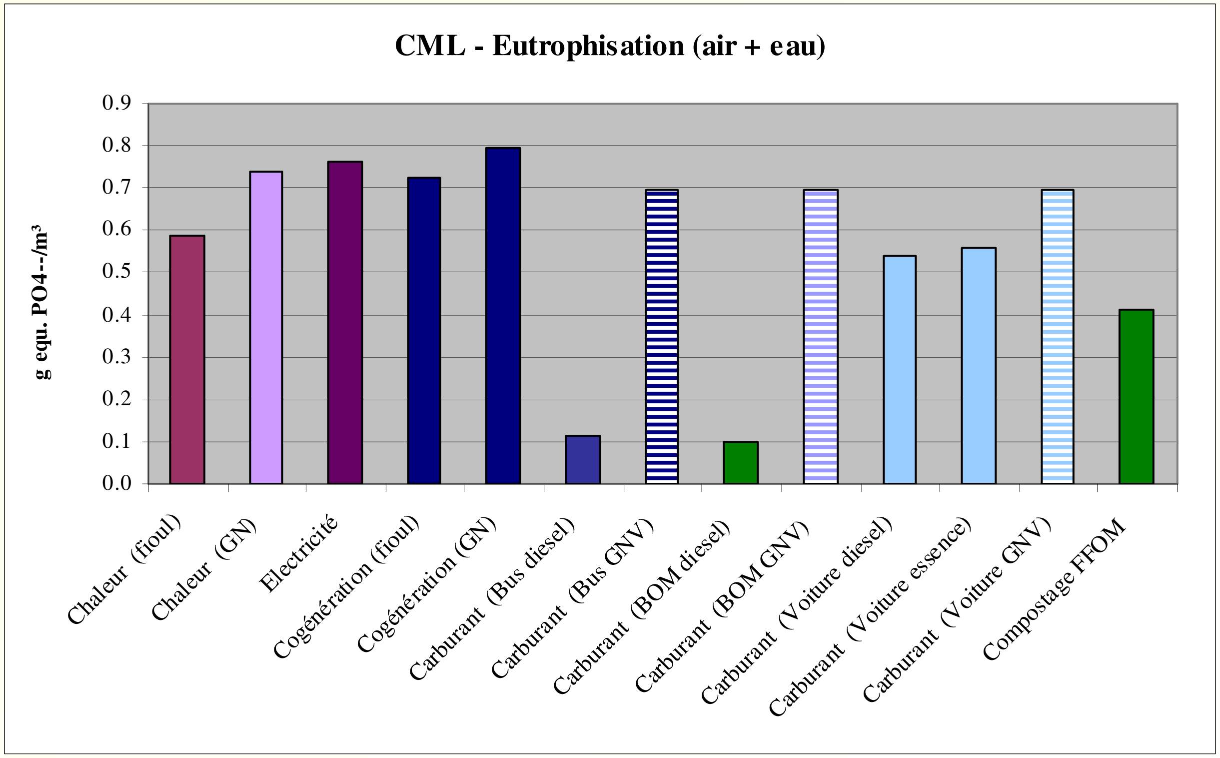
Main emissions (common to all valorisation methods) :

- NH_3 linked to composting and spreading of compost
- Avoided emissions of NH_3 and NOx during valorisation of the compost (no production of N, P and K fertilizers)

Main emissions (variable according to the valorisation method) :

- NOx and SOx during combustion of the crude biogas
  - ➢ Autoconsumption ≠ according to the valorisation methods
  - ➢ Quality of combustion ≠ according to the production units
- Emissions of NOx and SOx ≠ according to the type and quantities of substituted fossil fuels

Results : Eutrophication



No valorisation method leads to a net reduction of emissions of eq. g of PO4--

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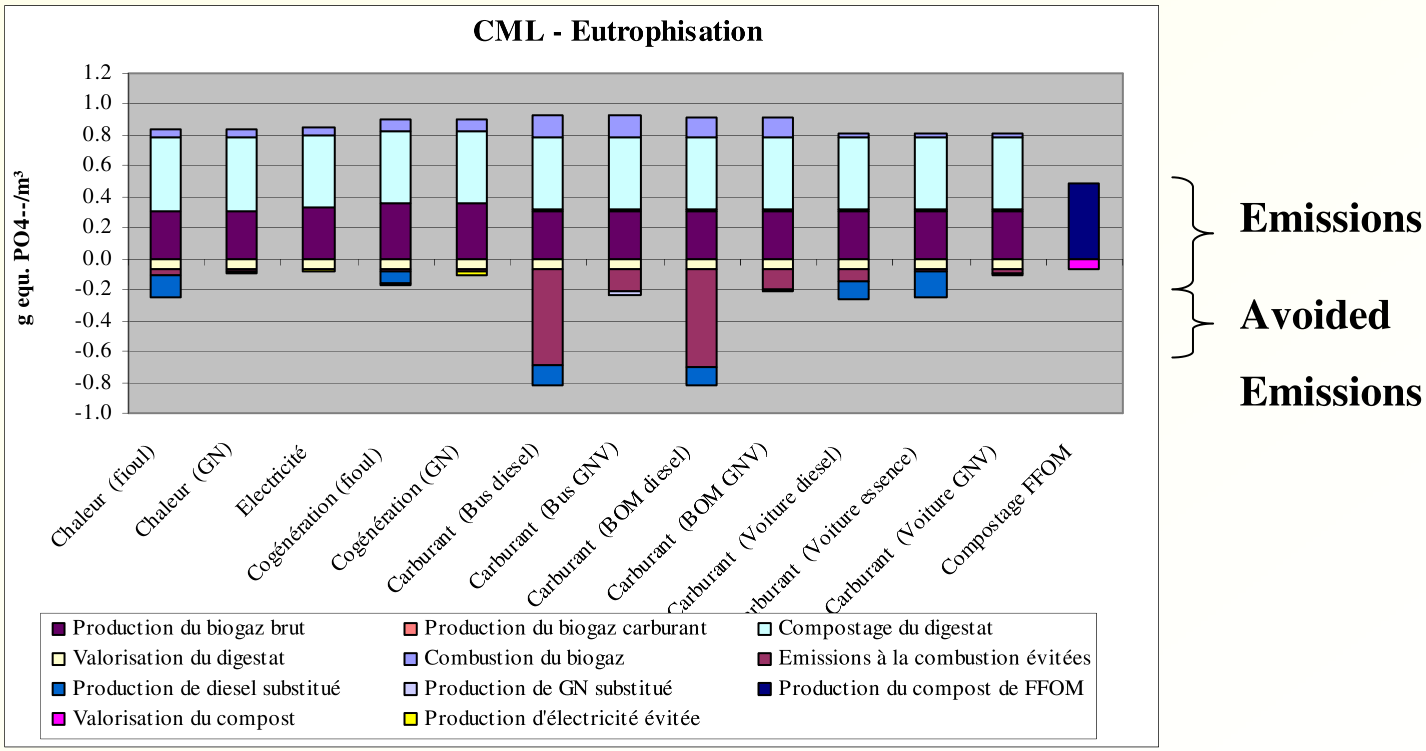
Results : Eutrophication



Significant emissions of N and P

- during biomethanisation (wastewater)
- from composting of digestate (N)

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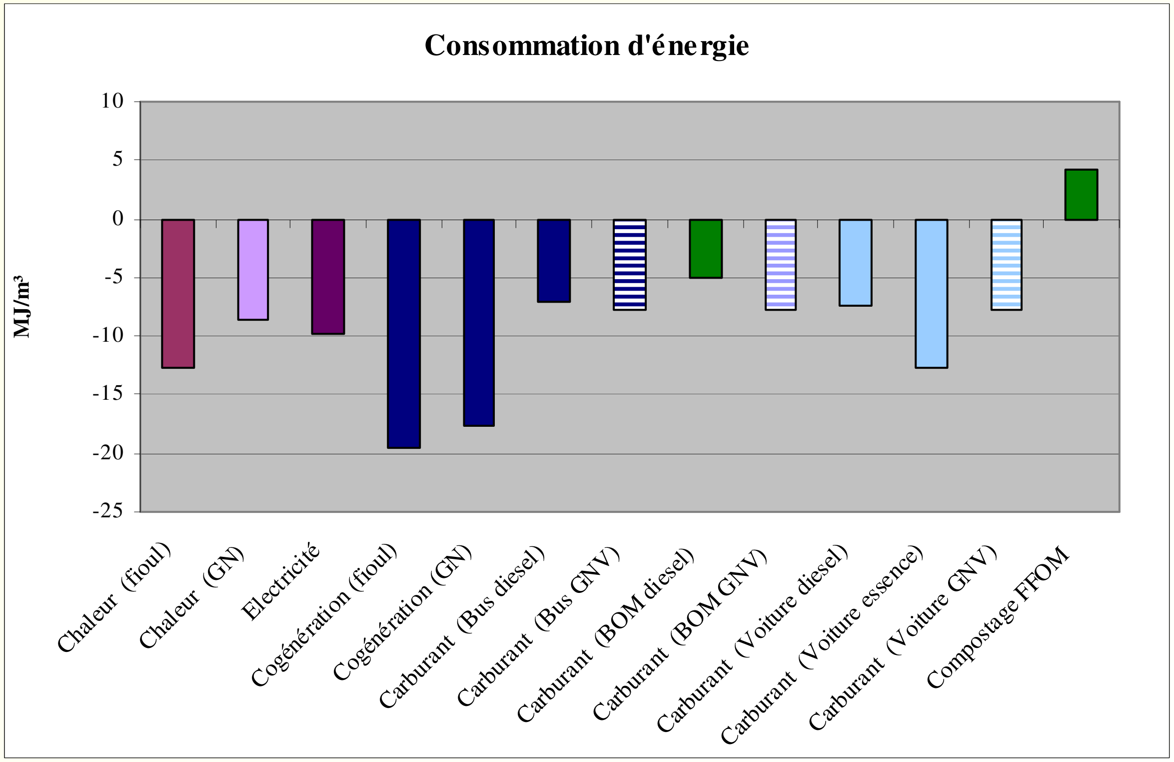
Results : Non renewable energy



From the point of view of the preservation of fuel resources, it is always more favourable to valorise biogas produced from PW. CHP is the best solution

Biomethanisation is preferable to composting in closed hall for all biogas valorisation methods

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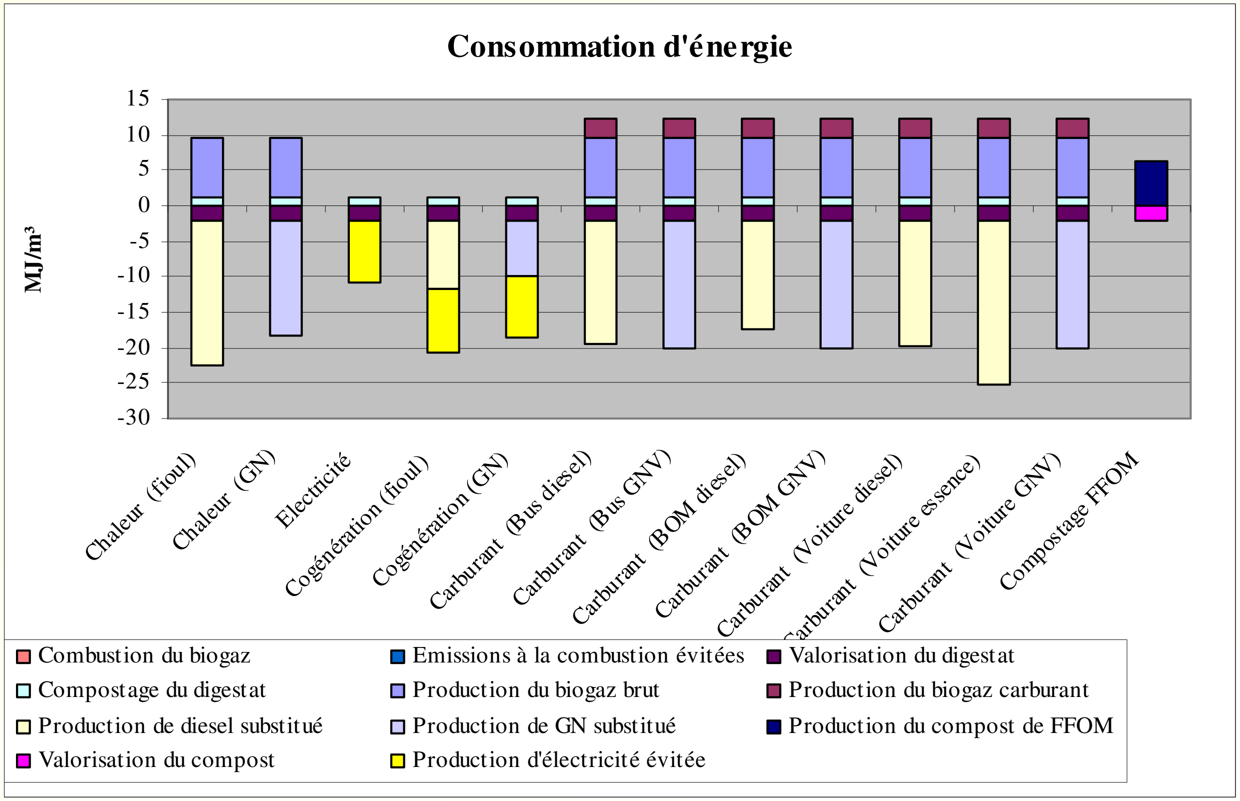
Results : Non renewable energy



As for GHG emissions, it is the differences in energy yield of the various valorisation methods that explain the differences

Results : Sensibility analysis

Uncertainty specific to each valorisation method

- Definition of the electricity mix
- Percentage of biogas burned in flare stacks
- Loss of biogas fuel

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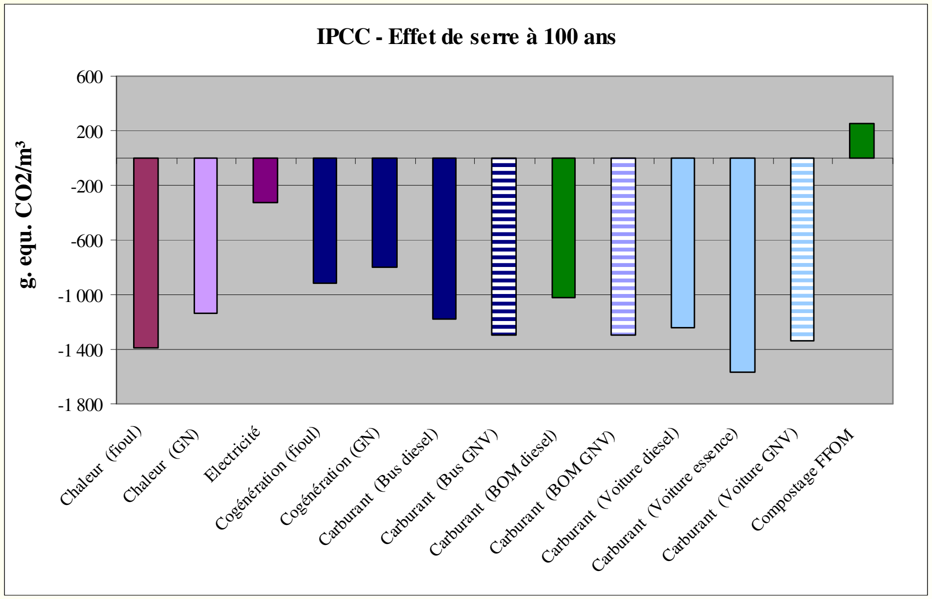
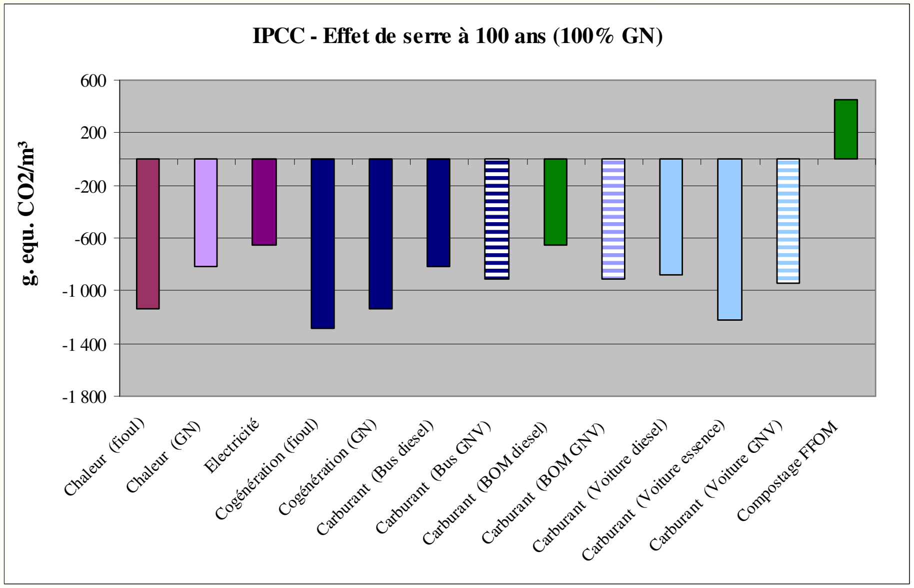
Results : Sensibility analysis

Choosing the right electricity mix

Average Mix



100 % NG



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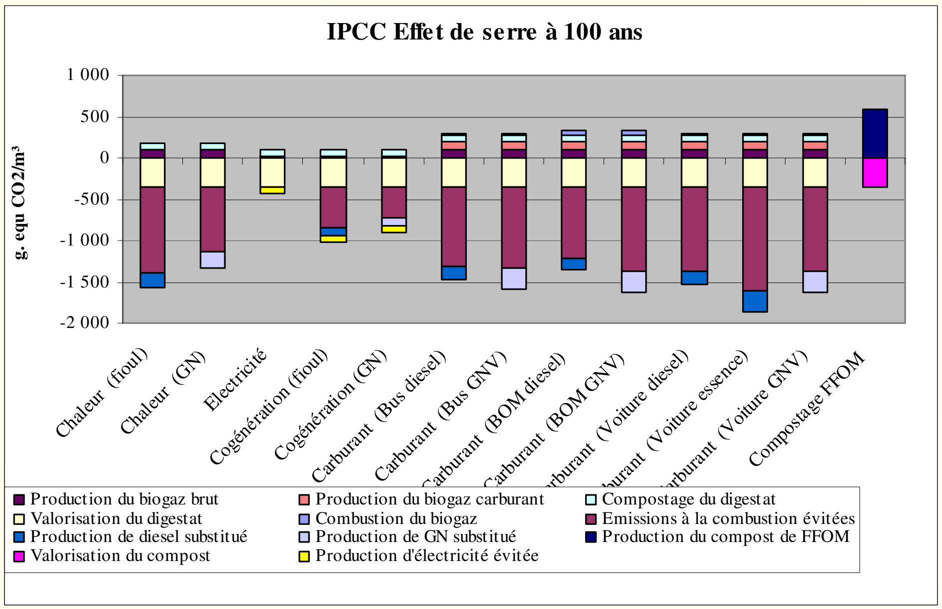
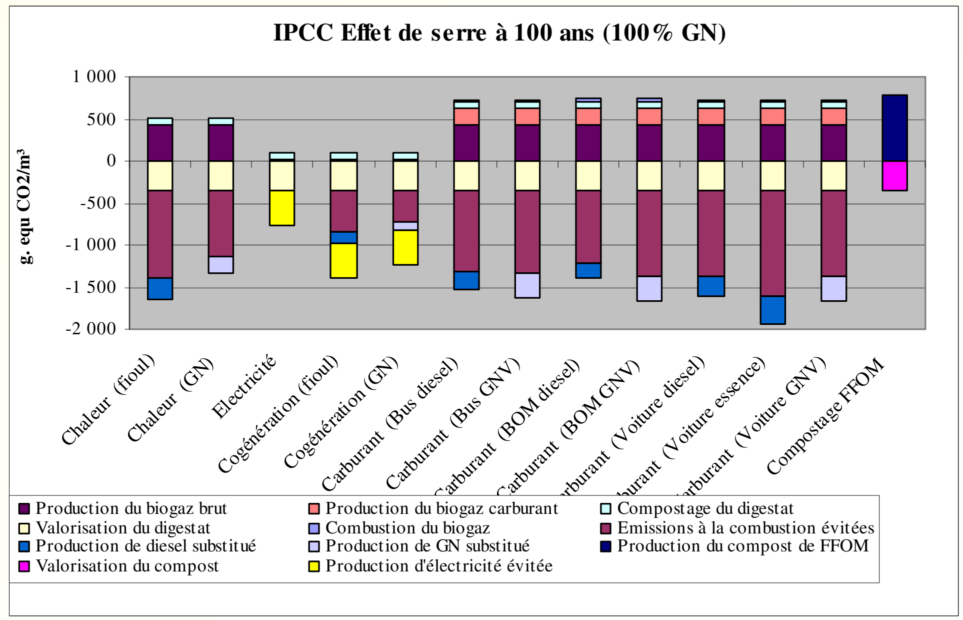
Results : Sensibility analysis

Choosing the right electricity mix

Average mix



100 % NG

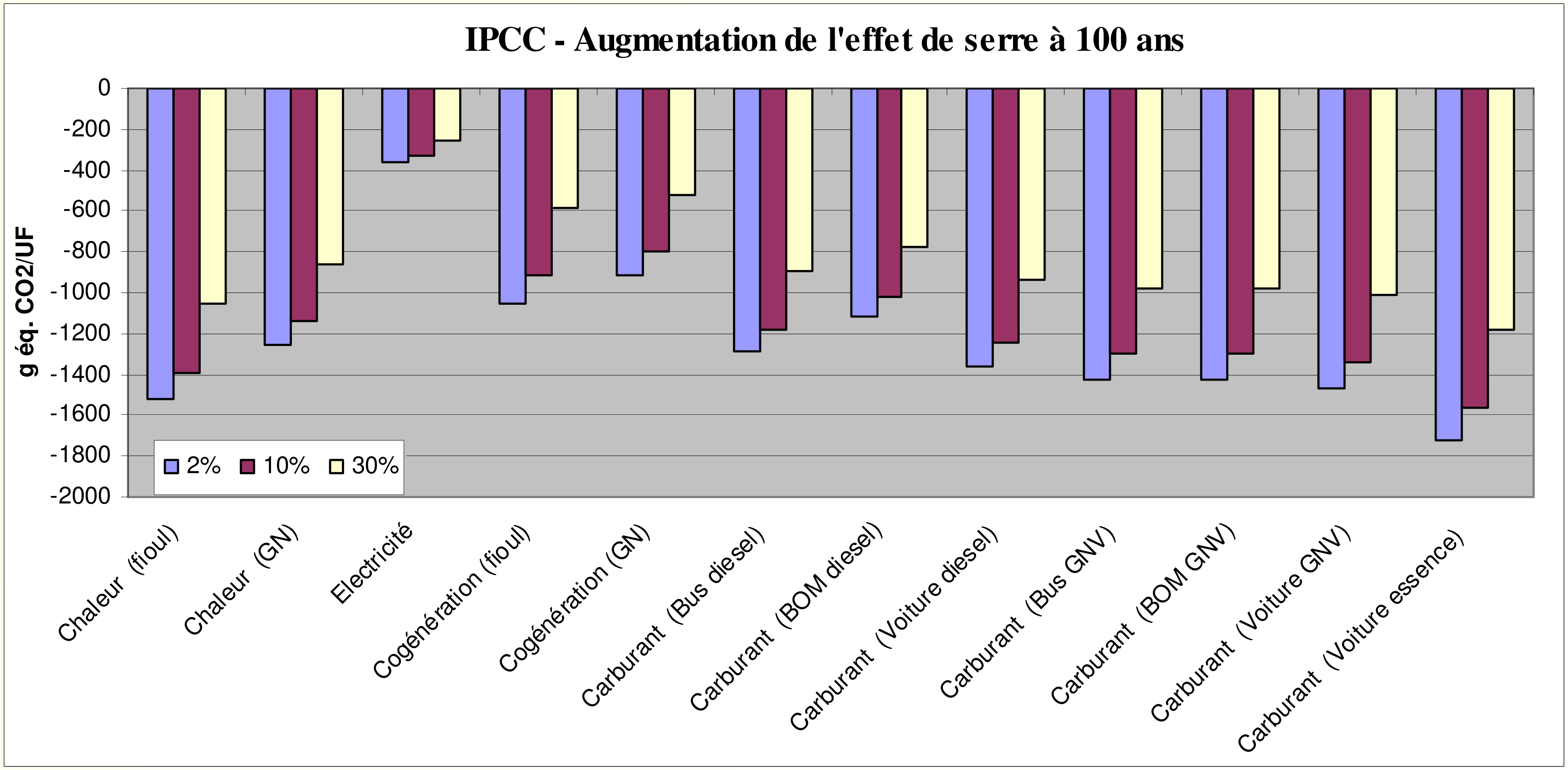


Main differences :

- ➚ emissions in the case of substitution of E_{elec}
- Greater impact for the production of crude biogas

Results : Sensibility analysis

Percentage of biogas burned in flare stacks



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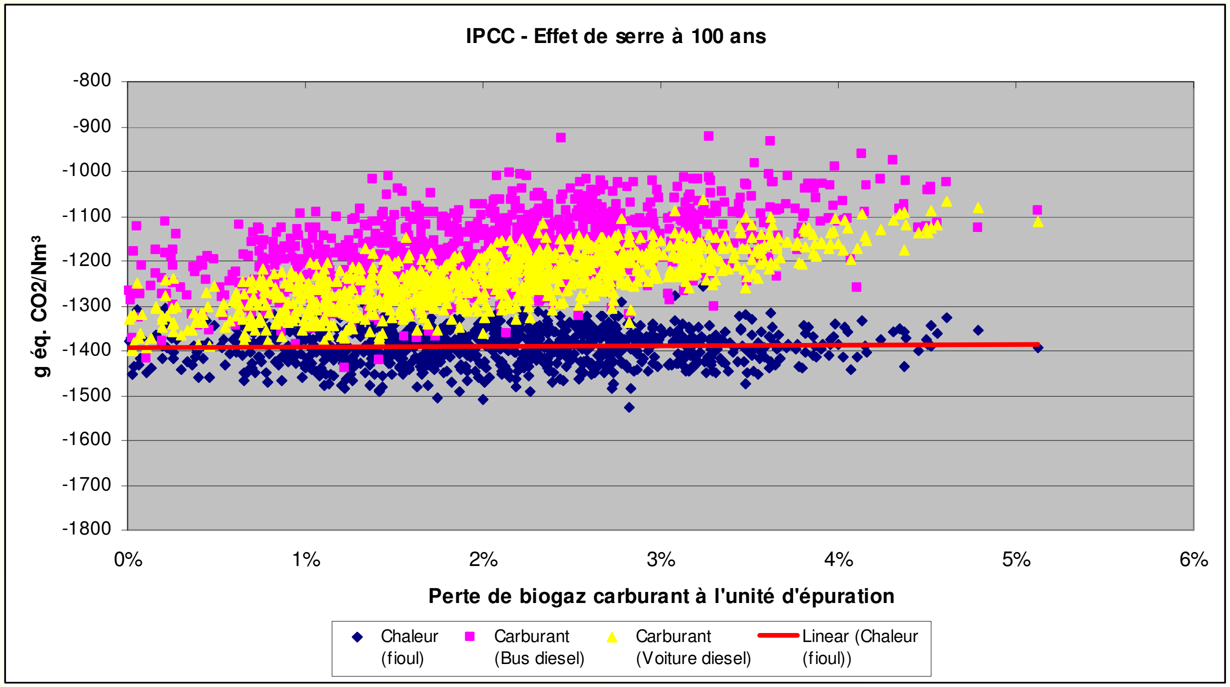
Results : Sensibility analysis

Loss of biogas fuel



- Valorisation as heat in substitution for domestic or heating oil remains preferable to valorisation as fuel for cars (yellow dots) or buses (pink dots) in substitution for diesel

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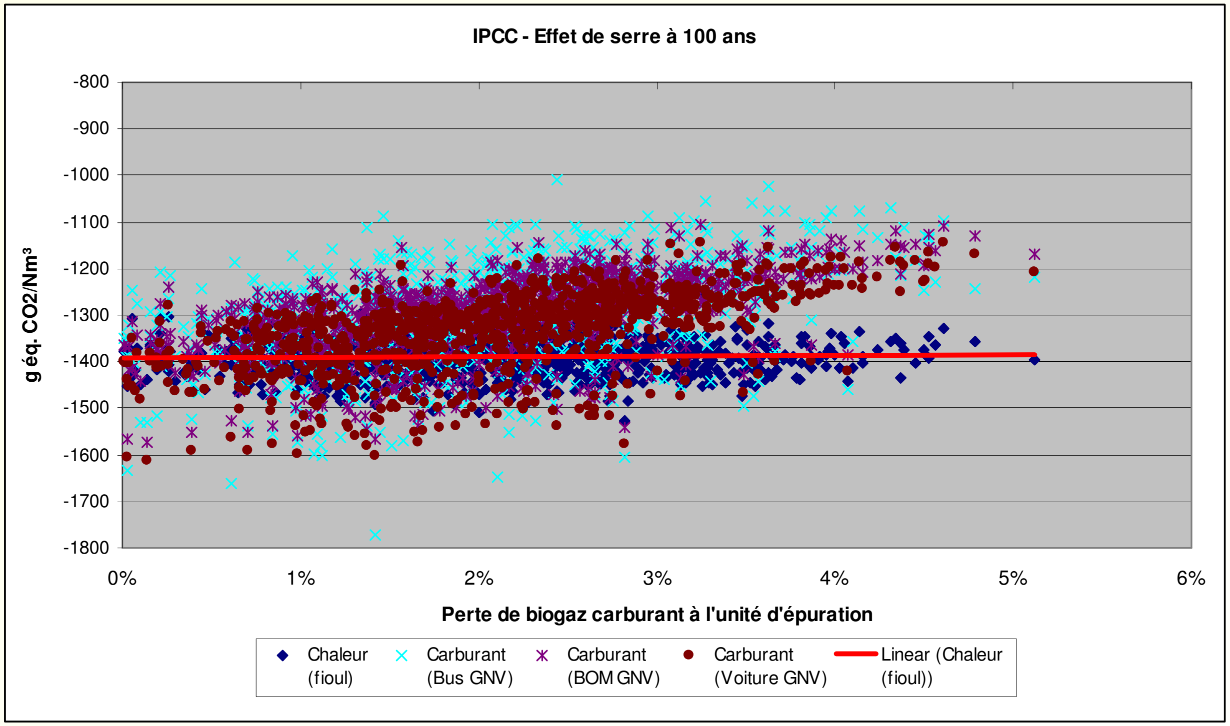
Results : Sensibility analysis

Loss of biogas fuel



If the losses of biomass fuel are limited to 0,04 %, the gap between valorisation as fuel for DRCVs or cars in substitution for NGV and valorisation in the form of heat in substitution for domeestic or heating oil becomes negligeable.

Conclusions

Comparison of valorisation methods (Q.1)

- **Increase of the greenhouse effect**
  - Valorisation of biogas as heat in substitution for domestic or heating oil and as car fuel in substitution for NGV are the best solutions
  - Valorisation **as electricity is the least attractive option**
  - These conclusions are influenced by :
    - **the electricity mix taken into account**
    - **the valorisation rate** (% burned at the flare)

Conclusions

Comparison of valorisation methods (Q.1)

- **Acidification of the atmosphere**
  - Valorisation of **biogas as a substite for diesel** in buses or waste collection vehicle (WCV) are the only way to bring about a significant reduction of acid emissions

Conclusions

Comparison of valorisation methods (Q.1)

- **Eutrophication of water**
  - No biogas valorisation method leads to a net reduction of emissions into the water
  - Valorisation **as fuel in substitution for diesel in buses and waste collection vehicle are** the least impact
  - These conclusions are influenced by :
    - **the amount of wastewater**

Conclusions

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Comparison of valorisation methods (Q.1)

- **Consumption of energy resources**
  - Biogas valorisation using **CHP** is the best solution
  - This conclusion is influenced by :
    - **the energy yields of the various valorisation methods**
    - **the rate of valorisation** (% burned at the flare stacks)

Conclusions

Comparison of valorisation methods (Q.1)

- **Between "combustibles" and "car fuel" :**
  - ✓ **Valorisation as biogas car fuel in buses or DRCV in substitution for diesel are the most interesting from the viewpoint of the 4 indicateurs chosen (greenhouse effect, acidification, eutrophication and energy).**

Conclusions

Comparison of treatment methods (Q.2)

	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	

Conclusions

Decision elements to be taken into account

- Favouring the valorisation method that offers the best use rate
- Limiting amount of wastewater in the biomethanisation process
- Ensuring the effective valorisation of the (metha)compost

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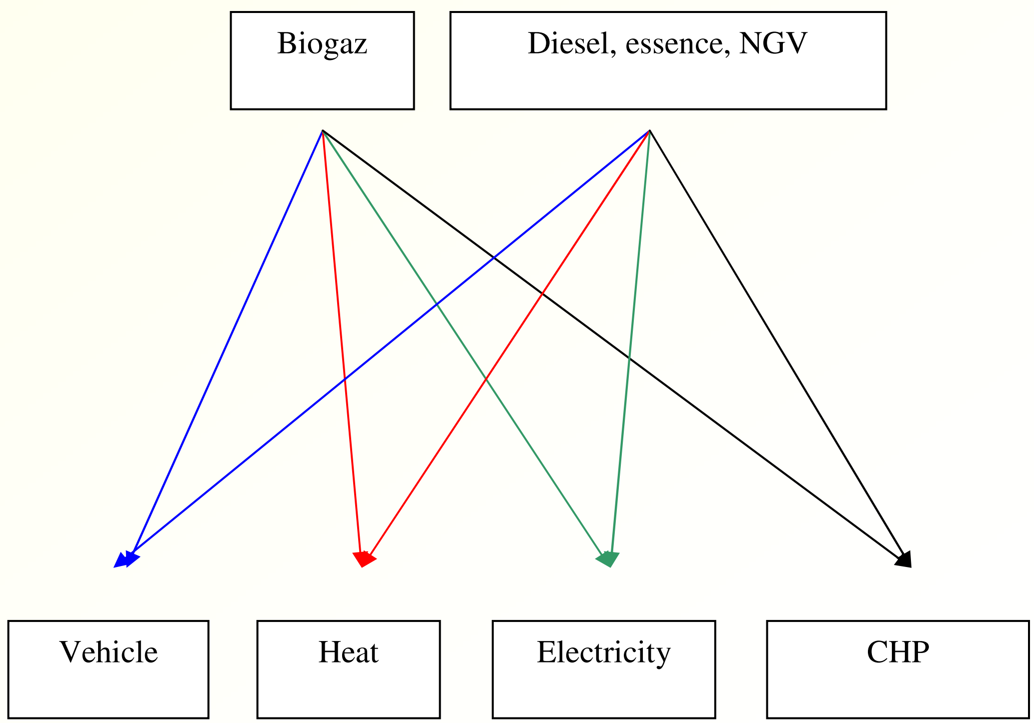
Objective of the study

Q. Biogas : Calculating the delta between the types of energy

Filière :

Valorisation method :



Data and assumptions - Biogas

Covering the energy requirements

	Thermal energy requirement	Electrical energy requirement
Valorisation as heat	Auto-consumption of crude biogas via a boiler (η 85%)	EDF network
Valorisation as electicity	Auto-cconsumption via a electric generator ($\eta_{élec.}$: 33%)	
Valorisation as CHP	Auto-cconsumption via a CHP unit (η_{therm} : 45 % ; $\eta_{élec.}$: 33%)	
Valorisation as fuel	Auto-consumption of crude biogas via a boiler (η 85%)	EDF network

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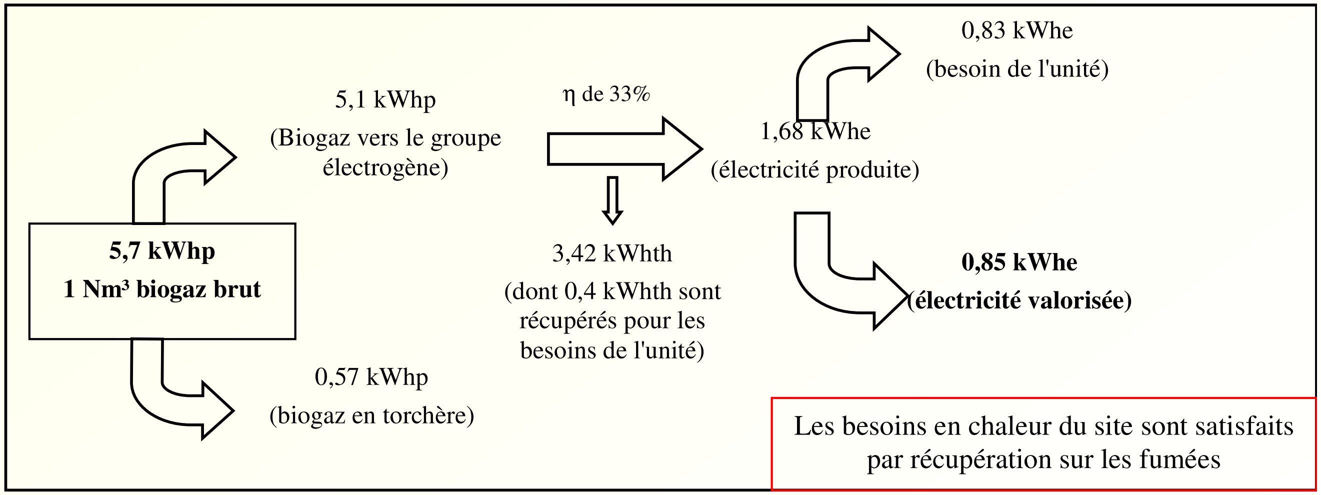
Data and hypotheses - Biogas

Energy balance - Valorisation as electricity



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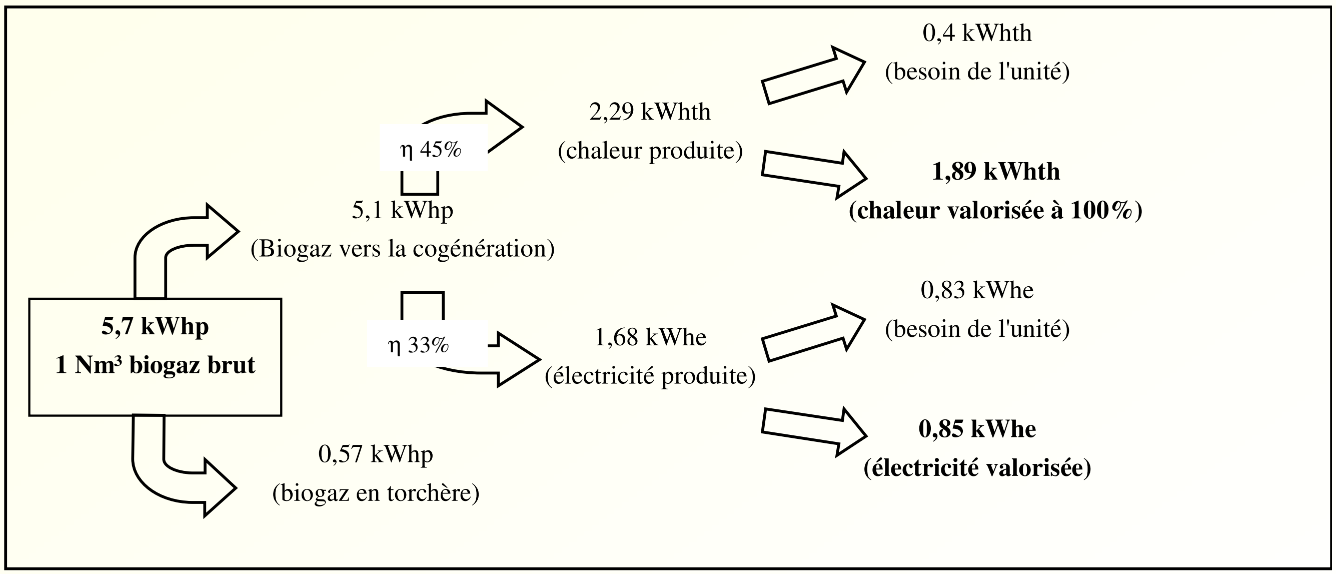
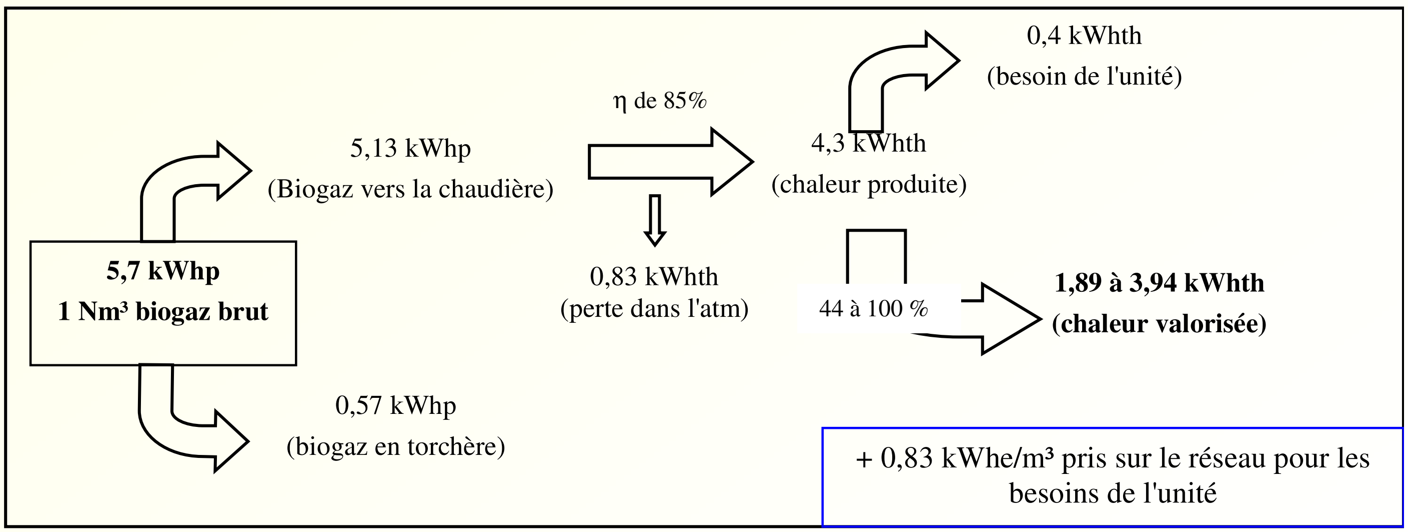
Data and hypotheses - Biogas

Energy balance - Valorisation as CHP



Data and hypotheses - Biogas

Energy balance - Valorisation as heat



Data and hypotheses - Biogas

Energy balance - Valorisation as fuel