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The Smart Use of Biogas: Decision Support Tool

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Abstract

Waste-to-energy provides a solution for two problems: waste management and energy generation. Anaerobic digestion is a biological process, thereby valorizing organic matter, usually fatal, produce a renewable energy source and digestates that can be used as fertilizer. Indeed, in the absence of oxygen (anaerobic digestion) and protected from light, organic matter is partially degraded by the combined action of several types of micro-organisms, a series of biological reactions leading to the formation of biogas composed of Carbon Dioxide (CO_2), Nitrogen N_2, Hydrogen H_2, Oxygen O_2, Water vapor H_2O, hydroxide sulfur H_2S and the energy recoverable portion Methane CH_4 but very harmful to the environment, or even 22 times more harmful than CO_2 which is a greenhouse gas (GHG). Once this portion of recoverable biogas containing methane CH_4 is produced or captured as much value it most effectively, however, different ways are possible: heat, power, Combined Heat & Power "CHP", automotive fuel or the injection into the natural gas network. The purpose of this work is to develop an Excel-based spreadsheet and database program with visual basic that can help to find the optimal scenario to valorize this biogas; firstly this scenario must be based on technical criteria as well as the flow of raw biogas produced, quality and purity of biogas required for each scenario. Secondly, the economic criteria also play an important role (treatment and valorization costs). Finally, this scenario chosen must take into account social and environmental impacts.

Keywords: Raw Biogas flow, Biogas valorization; technical – economical and environnemental studies; enriched biogas; biogas treatment modes; fossil CO2 emissions; Visual Basic; decision support tool; biogas flow; Heat Power and Biomethane selling prices.

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1. Introduction

The current use of fossil fuels is rapidly depleting the natural reserves. The natural formation of coal and oil however, it is a very slow process which takes ages. Therefore, a lot of research efforts are put into finding renewable fuels nowadays to replace fossil fuels. Renewable fuels are in balance with the environment and contribute to a far lesser extent to the greenhouse effect.

Nomenclature

PBT	payback time on investment
Inv	total investment cost in kilo euro (k€)
Rev	total revenues from energy sales in kilo euro per annum (k€/annum)
Co	total operation costs in (k€/annum)
GHG	greenhouse gas
X	molar fraction of methane
Y	molar fraction of carbon dioxide

1.1. Energy generation from biogas

Biogas is a renewable fuel and an energy source that can be applied in many different settings. It is defined as a combustible gas mixture produced by the anaerobic fermentation of biomass by bacteria and takes several days to form. In nature, the fermentation process occurs in places where biological material is fermented in an oxygen deprived environment such as swamps.

The main sources of biogas from human activities are domestic garbage landfills, fermentation of manure and raw sewage. The advantage of processing these waste products anaerobically, compared with aerobically, is the larger decrease in volume of wastes. For this reason, the industry nowadays prefers anaerobic fermentation to process waste streams.

Biogas mainly consists of combustible methane (CH_4) and non-combustible carbon dioxide (CO_2). Besides CH_4 and CO_2, biogas also contains small amounts of hydrogen sulfide (H_2S) and some other pollutants. The composition of biogas strongly depends on its source. Table 1 shows the composition of biogas from various sources, C.Aubry, 2010. It can be seen that biogas from a garbage landfill also contains some nitrogen (N_2). CH_4 combusts very cleanly with hardly any soot particles or other pollutants, making it a clean fuel. But CO_2, the non-combustible part of the biogas, lowers the calorific value of the biogas. Biogas containing 55% CH_4 has a calorific value of 21.5 MJ/Nm^3 while pure CH_4 has a calorific value of 35.8 MJ/Nm^3 this is the reason to remove CO_2 from raw biogas, J. D. Murphy et al., 2004 and J.C.Verchin et al.2010.

Table 1 Biogas composition from various sources

Biogas sources	CH_4 (%)	CO_2 (%)	H_2S (%)	Si (mg/Nm^3)
Garbage	55 to 60	40 to 45	0 to 0.5	0 to 50
Urban sewage sludge	60 to 65	35 to 40	0 to 1	0 to 20
Industrial effluents	55 to 75	25 to 45	0 to 1	0
Agro – food wastes	60 to 70	30 to 40	0 to 0.5	0
Agricultural waste	50 to 55	45 to 50	0 to 1	0
Landfills gas	40 to 50	25 to 40	0 to 0.5	0 to 50

1.2. Aim of the work

In favor of sustainable development engagement in many countries, many research programs were born under this topic. The FIMA laboratory in Algeria has decided to lunch an initiative research on the biogas valorization ways. The aim of this work is to develop and test a decision support tool to predict the best way to use biogas, this tool is called “Smart Biogas Decision Support tool, SBDS tool”.

1.3. Envisaged scenarios

Different scenario were envisaged, in fact we can use biogas for the production of heat, electricity, combined heat and power “CHP”, automotive fuel and the injection into the natural gas network. Fig.1. presents the summary of the biogas treatment and valorization , C.Aubry, 2010.

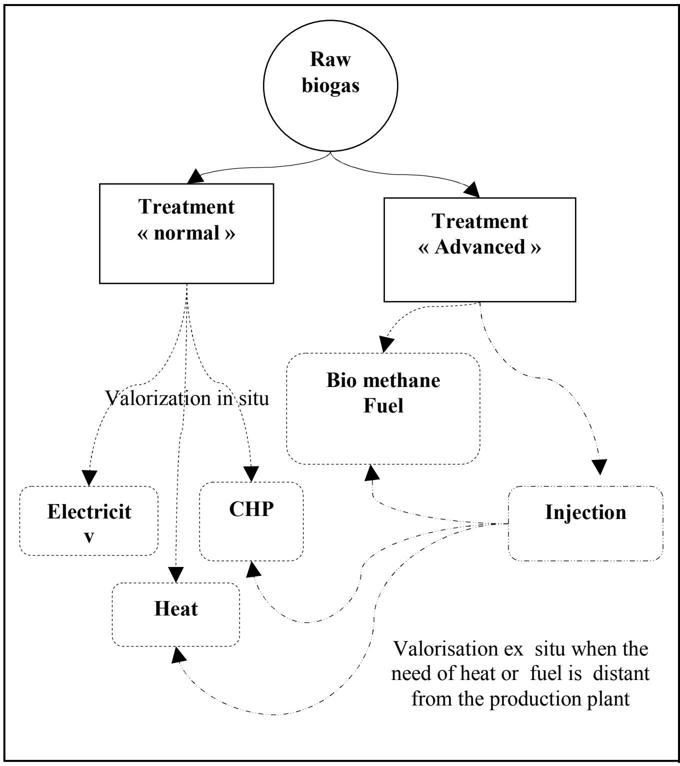


Fig. 1 Biogas treatment and valorization

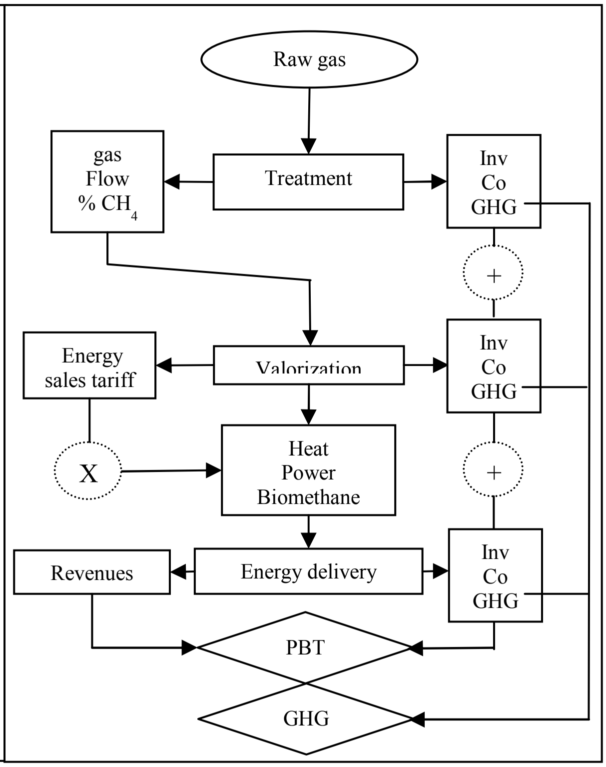


Fig. 2 Biogas calculation levels

2. Methodology

2.1. Integrated scenarios analysis criteria

The used method considers two main indicators to compare the integrated scenarios, the first may be defined as the result of a technical economic balance, while the second is obtained by the stoechiometric biogas combustion, and it is respectively the PBT and the avoided emissions of carbon dioxide, (CO_2). Equation (1) presents the PBT relation, P. Morin et al. 2010:

$$PBT = Inv / (Rev - Co) \tag{1}$$

The value of the Inv represents the sum of all eventual investments during the treatment, valorization and energy delivery processes; the Co value must include also insurance, human resources, maintenance, external energy and chemicals, E. Wusterhaus, 2010. Fig.2 illustrates the calculation key levels. The combustion of biogas give a biogenic CO_2 which continue its natural cycle, 1 kg of biogas give $\frac{(X+Y).44}{(X.16+Y.44)}$ kg of biogenic CO_2.

2.2. The SBDS tool principle

The integrated scenarios are compared based on economic, energetic and environmental criteria. The "SBDS tool" is an Excel-based spreadsheet and database program that calculates the pay back times on investment and CO_2 avoided emissions. SBDS tool provides extensive technical and economic information about integrated processes, from the incoming raw biogas to the final use of the energy. The investment, operation, and maintenance costs are estimated for each unit necessary for the process. Each scenario requires three mainly steps presented in Fig.3.

The integrated scenario start by introducing the flow of raw gas, and its quality regarding CH_4, CO_2 and H_2S content, this is the first step. The second step is the role of SBDS to make all calculations regarding the four different levels to obtain the PBT and the CO_2 avoided emissions. Those four levels are: biogas treatment, treated biogas valorization, energy generated and finally the energy delivery. Normally we can have two kinds of energy recovered from biogas valorization: heat and power, Technical document, 2006. But we can add a fourth level which is the kind of energy delivered into the natural gas network called bio-methane. The final step is the data output and their graphical representations.

3. The SBDS tool test

We have proposed to take an example of a digester which work under mesophilic conditions (35°c), the input wastes are manure, slurry and agricultural waste, the daily raw gas flow is about 3000 Nm^3/day or 125 Nm^3 / h, we have proposed for this simulation the values of 45 €/MWh for thermal energy selling price, and 100 €/MWh of primary energy for biomethane. The amount of 24 k€/annum was defined as the annual human resources salary. The values of these data will be discussed in the following section.

3.1. Results and discussion

Figures 4 (a) and 4 (b) were obtained with SBDS tool with the same input data considerations, they highlights the relationship between the raw gas flow and the energy delivery distance on the investment payback time.

For scenario "Heat", there is no profitable payback time if the raw gas flow is under 40 Nm^3/h and it is about 10 years, if we take the example of 125 Nm^3/h, the PBT is about 1,76 years with 1000 meter of thermal energy network according to graphic in Fig. 4 (b), if the distance is about 1000 meter, the PBT will be 3,75 years. The profitable case to make heat valorization is depending on the flow and also on the thermal energy delivery distance, a raw gas flow between 50 and 70 Nm^3/h can get a reasonable PBT between 4 and 6 years with 1000 m of grid distance.

For scenario "Power", the payback time is about 5 years with 125 Nm^3/h of raw gas; we can observe the stability in Fig. 4 (b) which means that there is no relationship between the PBT and the distance because the electricity delivery does not depend on the pipelines energy grid. However, the profitable PBT between 4 and 6 years with a range of raw gas flow from 80 to 130 Nm^3/h.

There is no profitable payback time under 50 Nm^3/h for "CHP" scenario with a distance of 1000 meters, the payback time will be between 6 and 4 years with a range of raw gas flow from 70 to 90 Nm^3/h and with no longer than 3200 m of energy delivery grid.

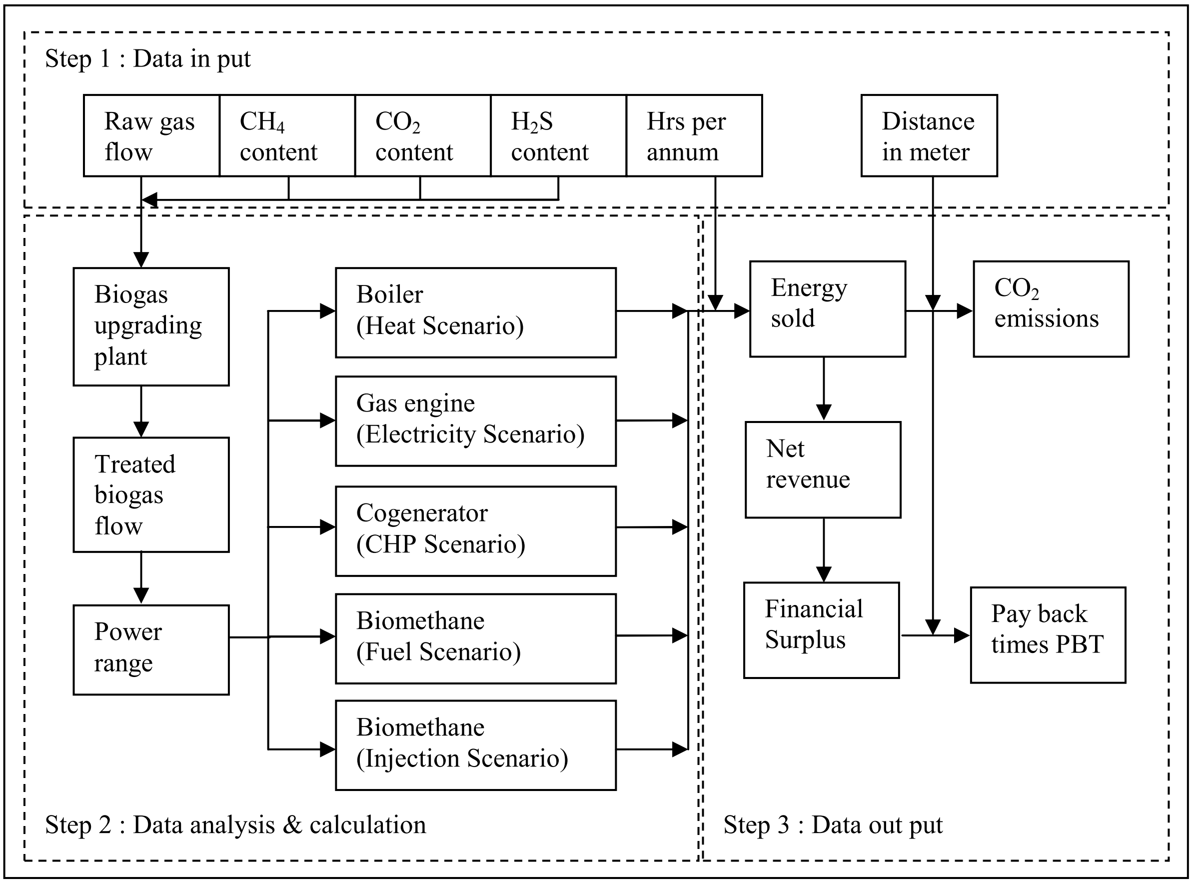
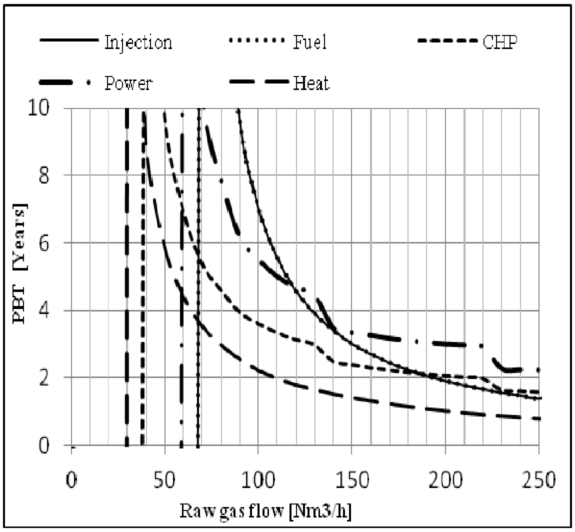


Fig. 3: SBDS tool key steps

For scenario “Fuel and Injection”, a payback time between 4 and 6 years can be obtained with a range of raw gas flow from 70 to 90 Nm^3/h and with no longer than 5000 m of biomethane network.



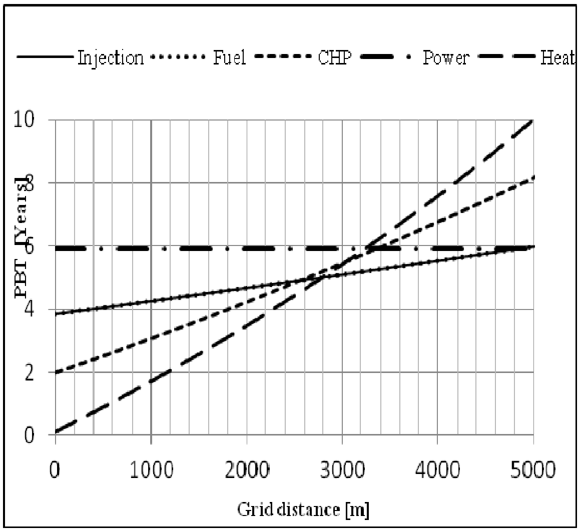


Fig.4 (a) Relationship between PBT & the raw gas flow (b) Relationship between PBT & the grid distance

4. Conclusions

SBDS tool, an Excel-based spreadsheet and database program was developed to calculates the investment and capital costs for biogas upgrading plants, valorization machine (Boiler and CHP motor) and it can determine the PBT on investment and estimate the GHG reduction for each investigated scenario. This tool was used to conduct the present study; variations in the input data gave different economic, energetic and environmental performances.

It is possible for a biogas production plant producing at least 50 Nm^3/h to make a heat valorization, a profitable PBT of 1,76 years was obtained with 125 Nm3/h; the delivery network plays an important role in the PBT determination, so a profitable one is obtained for less than 800 meter of thermal energy distribution network.

The “Power” scenario has a reasonable PBT of 5,5 years with a raw gas flow of 100 Nm^3/h even the thermal energy is not sold. The addition of thermal energy generation increase the revenues and makes a very favorable way of the biogas valorization, it has the PBT of 3 years even the distance of the thermal energy network is less than 1000 meters and with the condition that 100 % of the produced electricity and 100% of thermal energy are sold. Furthermore, the electricity obligation purchase makes very interesting to invest into power generation with biogas especially when the selling price is about 140 €/MWh.

The injection of biomethane into the natural gas grid is the favorable way to use biogas in a French context with an estimation of the selling price at 100 € / MWh, despite the high investment and running costs of the biogas upgrading plant (BUP), but it has the shortest PBT, and it avoid the maximum emission with 1521 ton of CO_2. The “Fuel” scenario has the same results with the “Injection” one because we considered that biomethane must be put into natural gas grid before selling it in the filling stations.The results obtained in this study could be generalized for each case of biogas valorization; a new database will be available once the new fees of the selling price will be ready.

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