PRE-FEASIBILITY STUDY OF A BIOGAS PLANT FOR PEYRELEVADE COMMUNITY

Pei Ling Koh[1], *Victor Pomarico*[1], *Venkata Phani Tadepalli*[1] *and Luis Rojas-Solórzano*[2]

[1]International Masters in Management and Engineering of Environment & Energy (ME3): École des Mines de Nantes; Royal Institute of Technology, Stockholm; Universidad Politécnica de Madrid; Queen's University Belfast; Budapest University of Technology and Economics
e -mail: pennykoh@gmail.com, vpuchoa@hotmail.com, nani.iitm@gmail.com,

[2] Universidad Simón Bolívar, Venezuela
e-mail: rrojas@usb.ve

***Abstract* - This work presents a technical and financial pre-feasibility assessment for heat generation from biogas for a retirement home in the community of Peyrelevade, France. The heat demand of the retirement home currently relies on fuel oil boiler and electric heaters. The biogas is to be produced mainly from grass silage. As result of the feedstock abundance in the community, electricity can be also generated in an 80kWe CHP unit operating in full power capacity. The electricity produced can be then sold to the national electricity utility in France. The financial analysis was carried out using RETScreen™. An efficiency of 62.9% is achievable in this CHP (Combined heat and power) biogas plant, with a total life cycle saving/income of 0.05€ for each MJ of heat supplied to the retirement home. A company set-up has also been proposed for the development of a community based company.**

Keywords - Grass Silage, Biogas, Boiler, CHP, RETScreen

1. Introduction

Worldwide many efforts have been made into renewable energies to compensate the energy demand increase as well as to decrease the harmful environmental effects of burning fossil fuels. The French government strongly promotes the development of renewable and clean energies, by giving incentives and hence making clean energy more attractive.

Biogas production and biogas potential from grass silage and animal residues offers environmental, social and economic benefits proving to be a sustainable solution for small rural communities.

The community of Peyrelevade is located west of the Massif Central, in the department of Correze and region of Limousin. Peyrelevade is a community member of RURENER, a project supported by the program Intelligent Energy from EU. This project is a network of small rural communities that want to reach energy neutrality at the local level [1].

The total residential energy consumption of Peyrelevade is around 974 toe/year [2]. out of which 80% is for heating purposes. The source of energy comes from wood, heating oil, electricity and LPG (Liquefied Petroleum Gas) . Electricity accounts for 16% of which 10% is used for heating. As the community is situated at a high elevation with colder climate as compared to other parts of France, energy for heating is the highest consumption in the community.

According to a report by RURENER [1], there is a great potential to generate energy from biomass, since there are already some experiences in the surrounding region of Peyrelevade for biomass valorization to produce biogas. The potential of biomass valorization to generate energy will be the key aspect of the next sections of the present work.

2. Problem Description

The main concern expressed by the community representatives was the fuel consumption for heating purposes. According to a survey carried out by ENSA – Clermont Ferrand [3], the insulation of the houses of Peyrelevade has been raised as a main concern leading to low heating energy efficiency. The required investments are the main barrier for householders to invest in the insulation of their houses.

An eventual operation to produce energy from biomass valorization could be implemented establishing a partnership between the community and farmers in the region. A project to generate cheaper and cleaner heating in the community level could bring environmental and social benefits on the local level. Therefore, a pre-feasibility of a clean energy project associated with heating production from biomass was decided to be the aim of our study.

With regards to the potential clients of the heating produced by this plant, the retirement home is a public building with high energy consumption, mainly for heating purposes, being an ideal client for the heating produced on this biogas plant.

Since the potential feedstock availability is higher than the retirement home heating demand, electricity can be also exported to EDF grid making benefit of feed-in tariff policies. Every producer of renewable energy with capacity lower than 12MW can apply to the national electricity utility, EDF (Electricité de France), to sell all the electricity produced at the rate fixed by the state. The regulation for the electric feed-in tariff for biomass valorization is the *«Arrêté du 10 juillet 2006 fixant les conditions d'achat de l'électricité produite par les installations qui valorisent le biogaz NOR: INDI0607869A»* (Statement of the 10th July 2006 laying down the terms of purchasing the electricity produced by biogas plants.) [4] The feed-in tariff for electricity generation from CHP plant with biogas injection is made up of 3 components: a) cogeneration rate, from 7 to 9 €ct/kWh depending on the power of the equipment, b) a methanation bonus of 2 €ct/kWh, c) An energy efficiency bonus (depending on the total efficiency) from 0 to 3 €ct/kWh.

3. Methodology

The following roadmap illustrates how the technical and economical pre-feasibility of a biogas plant in the community of Peyrelevade was carried out. Next sections are based on this methodology.

a) **Resource Assessment**: Assessment of feedstock availability and biogas production.
b) **Technology** and **Process Description:** Mass and heat balance, from raw material collection to heating production. First draft of the biogas plant focused on biodigester design
c) **Financial Modeling and Results**: Techno-economical model to assess energy production and financial feasibility.
d) **Project Impacts**: Social and environmental impacts in the community level.
e) **Company Set-up**: Recommendations to implement a company to operate the biogas plant.

4. Biomass Resources Availability

A significant amount of biomass is available in Peyrelevade, due to an extensive forest and green area all along its surrounding area. The feedstock to be used in Peyrelevade is grass along road in the surrounding area of the community. Some cow manure can also be used to form grass silage slurry, but this manure is available in a very small quantity. The following table describes the potential of biomass in the community of Peyrelevade.

Table 1. Feedstock availability in Peyrelevade

Grass Silage Availability Total area available for grass cuttings Road borders - 200 hectares Public lands - 150 hectares Average weight per area: 7,500 kg/hectare/yr Safety factor of harvesting: 0.9 Total Grass Availability - 2362 ton/ yr Dry Matter (DM): 886 ton/yr (38 %) Volatile Solids in DM: 686 ton/yr (78%)
Cow Manure Availability Total Cow Manure Availability: 20 ton/yr Dry Matter (DM): 3 ton/yr (15%) Volatile Solids in DM: 2.5 ton/yr (85%)
Total Biomass Available = 2382 ton/yr Total DM = 889 ton/yr Total Volatile Solids in DM: 688.5 ton/yr

For the collection of feedstock for Peyrelevade, the first process in the production of silage is mowing and harvesting the grass. The grass is wilted just enough to remove excessive moisture or add chemical inoculants to the harvested crop to aid the ensiling process. The cut grass is transported to where the silage is to be made. This will be done in a covered yard site near the retirement home. In the storage facility the grass is deposited in a heap (the clamp) and pushed up by a handler into a large pile. Special attention has to be made to ensure that air cannot get into the clamp, either from the top or around the edges. If air does get into the clamp the grass will not ensile properly and the resultant silage is less suitable for methanation.

The collection of the grass, transport, silage production and the storage process are proposed to be carried out once a year for the Peyrelevade community.

5. Technology and Process Description

The central part of an anaerobic biogas plant is an enclosed tank known as the digester. This is an airtight tank filled with the organic waste, and which can be emptied of digested slurry with some means of catching the produced gas [5]. Operational parameters such as HRT (hydraulic retention time), mixing, number of tanks and temperature along with the properties of the feedstock form the basis of digester design [6]. Taking into account all these factors we propose for the use of one stage batch digester. In one-stage digestion all the microbiological phases of anaerobic digestion occur in one tank. The one stage system is very popular at industrial scale because of the simplicity in operation, reduced costs and lesser technical problems. HRT of 25 days is considered for the whole batch operation.

Table 2. Biogas Production in Peyrelevade

Specific Methane Yield
Grass Silage - 453 m^3/ton ODM
Cow Manure - 255 m^3/ton ODM
Efficiency of Biogas Removal : 0.9
Total Biogas Collection:
(453 *886*0.9) + (255*3*0.9) = $3.6*10^5$ m^3

The heat produced by the biogas combustion will be used for heating a surface are of 2,500 m^2 of the retirement home and to supply heat to the biodigester, since the methanation occurs ideally within a range of 35-37 deg C. A CHP is proposed to generate electricity to be supplied to the grid.

Table 3. Biogas plant with a CHP Unit

80kWe nominal electric output.
Overall efficiency: 62.9%.
Assuming that 10% of the total gross energy of the biogas is supplied to heat the biodigester.

According to Ludington [7], the heating value of biogas depends on the methane yield, varying from 14.3 MJ/m^3 for 40% of CH_4 by volume to 25.1 MJ/m^3 for 70%. The methane yield of 58% in terms of volume fraction comes from the research carried out by Prochnow [8] identifying the methane yield of biogas from grassland depending on region, grass species, cutting period and intensity of grass management. For Peyrelevade case, the LHV (Lower heating value) used is 21.9 MJ/m3, based on a methane yield of 58%.

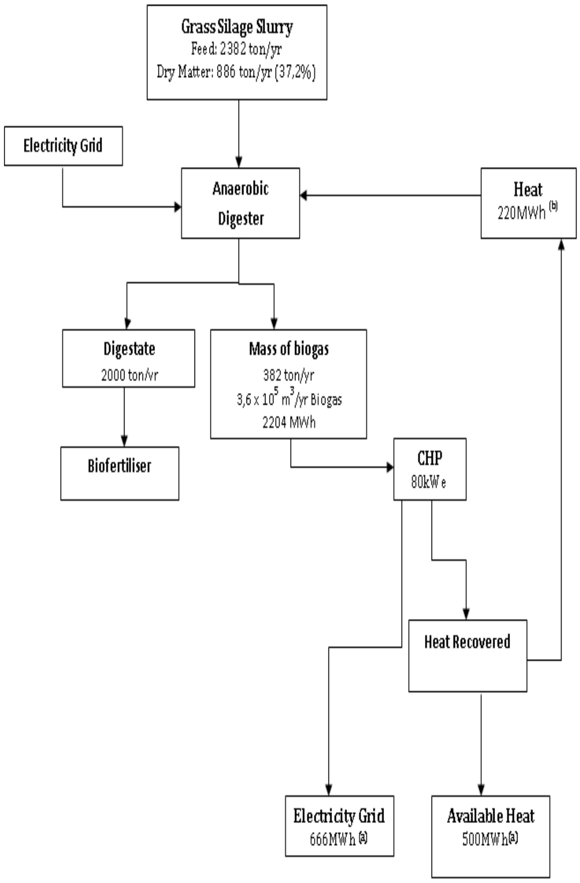

Figure 1. Heat and Mass Balance of Biogas Plant
(a) RETScreen Energy Model Calculation
(b) Assuming that 10% of the total gross energy of the biogas is supplied to heat the biodigester

As depicted in Figure 1, the total heat to be provided to the retirement home is 5000 MWh with 220 MWh is supplied back to biodigester in order to keep the minimum temperature requirements for methanization. The total amount of feedstock per year is 2382 ton. The HRT which is the time the slurry remains in a constructed batch digester is 25 days. Assuming a period of 5 days for the removal of the digestate and feeding in the next batch of biodigestate there will be 12 batches for biogas production in a year. Usually in a bioreactor the batch content is around 50 % of the total volume of the reactor and the remaining 50 % volume will be used for biogas storage [9]. Taking into account all the considerations mentioned,

Volume of the biodigester = 2 * (Mass of feed material/No of batches per year) * (1/density of silage) * safety factor

The density of the silage is calculated as 603 kg/m^3

Volume of the biodigester = 2 * (2382/12) * 1000 * (1/603) * 1.2

= 790 m^3

6. Financial Modeling and Results

The following financial assumptions were made:

- Project lifetime: 15 years, corresponding to the CHP total lifetime.
- Fuel escalation rate of 3.0% and inflation rate of 2.0%. The discount rate is 7.5%.
- Incentives from government: 35% of total capital costs.
- Debt ratio of 40% with an interest rate of 4.9% and term of 10 years.
- Feed-in tariff of 13.0c€/kWh.
- Fuel Oil cost of 0.54€/L.
- Electricity price in 2009 paid by the retirement home: 0.079€/kWh [3].
- Effective net income tax in France of 34.33% with no loss carry forward.

The total initial costs of this installation are €529,586. The equity accounts for 25% representing total initial investments of €132,396 from the shareholders. Table 4 splits capital costs in its components or work-packages.

Table 4. Breakdown of Relevant Capital Costs

Work package or Component	Costs (€)
Feasibility Study	12,600
Development	26,520
Engineering	36,000
Training & Commissioning	7,200
Tanks, Feedstock Storage, Gas holder	190,560
Power System (CHP 80 kWe)	124,500
Mechanical Equipments	35,730
Pipework	30,000
Building & Yard	40,000
Contingencies	25,156
Interest During Construction	1,320
Total	529,586

The revenues of this plant rely mainly in the electricity sold to the utility grid with the applicable feed-in tariff. The heat to be provided to the retirement home will be without charge. On the other hand, the monthly savings of the avoided fuel oil and the electricity currently used for heating purposes in this retirement home is considered as indirect revenues. The annual Life Cycle Savings and Income, taking into consideration the avoided fuel costs and electricity sold to the grid, is c€18/MJ, which corresponds to total saving per year of €121,901. This pre-feasibility assessment states a yearly positive EBIT (Earnings before interests and taxes) of €83,264, by deducting the O&M costs and the needed fuel for peaking conditions of the retirement home. Table 5 demonstrates the split of the O&M costs of this plant.

Table 5. First year Profit and Loss in €

Electricity Sales	+ 86,549
Avoided Fuel Costs	+ 35,352
Total Life Cycle Savings and Income	+121,901
O&M Costs	- 36,294
Fuel Costs for Peak Load Conditions	-2,343
EBIT	= 83,264

The forecasted profit and loss of this plant are summarized in the Table 6.

Table 6. Breakdown of O&M costs

O&M Work-package	Costs (€)
Methanation Unit	2,144
Feedstock Transport	2,382
Power/Heating System	15,978
Disposal of Biodigestate	8,004
Feedstock Pre-Treatment	2,382
Reactants for Biodigestion	953
Utility Bills	1,191
General & Administrative	1,533
Contingencies	1,728
Total in year 1	**36,294**

The project's cash flow is satisfying with significantly increase after the debt is entirely paid back. The accumulated cash flow is positive in the end of the project accounting for €525,349, and the equity payback occurs in between years 3 and 4, as illustrated in Figure 2.

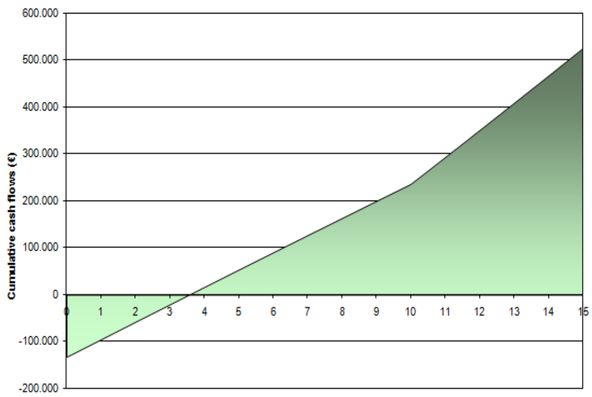

Figure 2. Accumulated Cash Flow

The financial results for this project are satisfactory, with an IRR (Internal rate of return) after tax of 8.4% for the whole project and 28.2% for the project's equity. This significant difference relies on the incentives considered for the simulation. The benefit-cost ratio illustrates that the present value of the accumulated cash flow is 1.74 times higher than the investment, an excellent net present value per euro initial outlay. Taking into consideration that the main goal of this project is the social and environmental benefit, this represents still a very interesting option in the financial point of view.

Electricity export rate (feed-in tariff) and the avoided costs of fuel and electricity currently used as heating source are directly related to the income sources of the project. Small variations on these values can significantly impact the financial results of the project. For this pre-feasibility assessment, we assumed a conservative feed-in tariff of 13c€/kWh, based on the methanation bonus and efficiency rules as above mentioned. Nevertheless, the efficiency could be increased, since the heat is partially not recovered, by either expanding the heating network or enhancing the heating usage for domestic water, making benefit of the recovered heating also during hot seasons. In the same wavelength, an increase in the oil prices as consequence of the non-stable market of fossil fuels could bring positive impacts to the project, since fuel costs represents savings of the avoided fuel oil and electricity by undertaking this project. The Table 7 is a sensitive analysis of the project's IRR by varying the feed-in tariff as well as fuel costs.

7. Environmental and Social Impacts

Heat and electricity generation from biogas plant will decrease dependency on electricity and fuel oil at the same time decreasing the amount of GHG by 170 t of CO2eq or equivalent to 31 cars not used per year.

In terms of social impacts, the biogas plant will contribute to socio-economic improvement of the project area in form of

- Job creation
- Revenue generated from electricity sold to EDF (feed-in tariff)
- Technological and skills transfer through local workforce training and implementation of new processes and technologies in biogas production.
- Contribution to continuous pursuing of energy neutrality
- Encouraged sustainability development at the community level.

8. Company Set Up

This project is supposed to be developed by a legally independent company which will own the biogas unit as well as the cogeneration system. It is suggested to set up a Local Public Corporation for the community to legally own the biogas plant and operate it. Revenue generated will be used for other benefits of the community at the same time increasing employment opportunity.

The corporation will be the entity in charge of the organization, O&M of the plant, paying taxes, payroll obligations and charging service to third party such as composting of digestate.

It is important to secure as much as possible the links between the project developer and the other stakeholder of the project. The project is planned for 15 years; here is a list of contracts that should be defined:

a) Purchasing contract: a legal agreement should guarantee the local farmers to keep their commitments to supply the manure. The contract should define the frequency and price review.

b) Agreement with EDF: to ensure good connection to electrical grid and especially to guarantee the purchasing price of electricity by EDF.

c) Agreement on composting: in case, the solid fraction of the digestate is not treated on site, it must be composted. The condition for outsourcing must be precisely defined in a contract, reducing the risk that the compost plant refuses the digestate produced by the plant.

d) Construction contract: specifications and requirements must take into account the materials and the technique used. The request of quality and the planning.

e) Procurement contract: Equipment procurement contract is important to ensure that the entire requirement based on the design is met by the equipment supplier. Date of delivery and payment method should be specified.

f) Maintenance contract: it enables to outsource the maintenance and any kind of risk that is linked to maintenance. It is necessary to find a company that accepts to take in charge the maintenance for 15 years and to take responsibility.

9. Conclusion

A pre-feasibility assessment has been conducted for the usage of grass silage and animal manure for the production of biogas which can be further used for meeting the energy needs of Peyrelevade community. The analysis shows promising financial results. The analysis also emphasized the social aspect of the project, bringing employment and additional tax incomes on the local economy level. From the environmental point of view, a biogas plant valorizes the excess of grass and manure available, generating energy from waste and decreasing the carbon footprint of Peyrelevade.

9. Recommendations for future work

Further steps needs to be taken for the development of this project.

CHP Proposal: This proposal needs a full scale feasibility study regarding various aspects such as availability of feedstock, location of the biogas plant, operational and technical aspects related to the process development, various commissioning activities, in depth financial analysis by contacting various companies supplying the required equipments.

Feedstock: For the success of any biogas plant, detailed characterization of the feedstock is very important. Quality control of the feedstock is the most important way of ensuring a quality end product.

Waste Heat Recovery: The efficiency of the CHP plant for the recovery of waste heat needs in depth analysis since for the Peyrelevade case effective waste heat recovery is the main objective. The exhaust gas temperature, specific features related to the reciprocating engine, heat exchange network for providing heat to the biodigester are to be investigated. The heat recovery affects the overall efficiency of the system, which defines the bonus of the feed-in tariff. This bonus will support the financial performance of the plant.

Digestate Utilization: Various standards regarding the utilization of digestate produced by anaerobic digestion have to be assessed. Chemical quality assessment of the digestate in terms of elements such as Nitrogen, Phosphorous and Potassium needs to be done. Disposal of this digestate can be expensive and can affect the financial viability of this project if proper analysis will not be done. Finding a location for composting the digestate by the community itself and selling the resulting fertilizer may present a good solution.

Company Set up: All the information regarding this project has to be presented transparently from time to time to various stakeholders involved. The entire set up of the company and the various activities the community would like to take under itself needs detailed discussion among the members of Peyrelevade.

10. Acknowledgements

The successful undertaking of this project would not have been possible without the collaboration and assistance received from our local contact Aline Brachet from RURENER, Pierre Coutaud and Jean Guérin from Peyrelevade community.

We are also indebted to Florent Chazarenc, coordinator of the ME3 Master's program at the Ecole des Mines de Nantes, for his professional support throughout the project.

11. References

[1] RURENER. Commune de Peyrelevade - L'etat de lieux RURENER en matiere de neutralite energetique. s.l. : RURENER, 2009.

[2] Explicit; ISL. Etude territoriale énergétique du Parc Naturel Régional de Millevaches. 2005.

[3] Coutarel, Jean-Louis and Vedrine, Corine. Etude sur la commune de Peyrelevade. Clermont Ferrand : ENSA, 2009/2010.

[4] Le ministre de l'économie, des finances et de l'industrie et le ministre délégué à l'industrie. (2006). *Décrets, arrêtés, circulaires.* France: JOURNAL OFFICIEL DE LA RÉPUBLIQUE FRANÇAISE.

[5] J.B. Holm, T. A. Seadi and P. O.Popiel, "The future of anaerobic digestion and biogas utilization", Bioresource Technology, Volume 100, Issue 22, Pages 5478-5484, November 2009.

[6] A.S.Nizami, J.D. Murphy, "What type of digester configurations should be employed to produce biomethane from grass silage?", Renewable and Sustainable Energy Reviews, Volume 14, Issue 6, Pages 1558-1568, August 2010.

[7] Ludington, David. *Calculating the Heating Value of Biogas.* Ithaca, NY : DLtech, Inc.

[8] L.David, "Calculating the Heating Value of Biogas", Ithaca, NY : DLtech, Inc.

[9] N.S.Green, "Emerging biodigester technology in Honduras : Biophysical processes and Operation", December 2005.

Table 7. Sensitive Analysis of IRR (Feed-in Tariff x Fuel Costs)

		Fuel Costs				
		-10%	-5%	0%	+5%	+10%
Feed-in tariff	-10%	5.2%	5.8%	6.3%	6.9%	7.4%
	-5%	6.3%	6.9%	7.4%	7.9%	8.4%
	0%	7.4%	7.9%	8.4%	9.0%	9.5%
	+5%	8.4%	9.0%	9.5%	10.0%	10.5%
	+10%	9.5%	10.0%	10.5%	11.0%	11.5%

(shaded) IRR lower than discount rate of 7.5%