XI-026 – POTENTIAL BUSINESS CASE FOR SMALL-SCALE BIOGAS PRODUCTION IN CURITIBA

Semida Silveira(1)
KTH Royal Institute of Technology. PhD in Regional Planning KTH. Head of Energy and Climate Studies, Dept of Energy Technology.
Simon Björklund (2)
Master of Science Industrial Economy, KTH.
Niklas Öhman (3)
Master of Science Industrial Economy, KTH.

Address(1): Brinellvägen 68, 100 44 Stockholm, Sweden - Tel: (46) 8 665-9969 - e-mail: semida.silveira@energy.kth.se

ABSTRACT

The City of Curitiba produces 2 500 tons of MSW (municipal solid waste) per day, and most is landfilled. At present, biogas production is being introduced using a large-scale commercial plant with substrate from sewage sludge and food waste. However, there are other options for developing biogas production in the city and adding value to the municipal organic waste. In this study, we investigate the feasibility of biogas production from anaerobic digestion (AD) using a small-scale decentralized biogas plant connected to a local food market. The technological options for biogas production are evaluated in relation to the highest investment cost admissible to obtain a positive net present value of the prospective investment. Estimations of investment costs were gathered from the literature, and the specific conditions for implementation of such a project were evaluated on-site. We found that wet digestion in a floating-drum or tubular digester is suitable for small scale applications in Curitiba. Small-scale decentralized biogas production is an economical and socially viable option. This is good news, as an initial small-scale project can pave the way for small and medium enterprises in the metropolitan region. The sensitivity analysis showed that the amount of organic waste available and the price of commercialized products would have most economic impact on a potential project. It is recommended that a small-scale plant is established adjacent to Mercado Regional as a model to be replicated. At the same time, the municipality should explore ways to improve the efficiency of waste collection, and improve specific data on compositions and quantities of different waste flows so as to support the development of biogas business, improve the waste management system of the city and reduce emissions from solid waste.

KEY WORDS: Solid waste, biogas, anaerobic digestion, small-scale.

BIOGAS OPPORTUNITIES IN THE CITY OF CURITIBA

The Brazilian National Waste Policy (BNWP) establishes requirements for waste management practices (International Finance Corporation, 2015). In this context, cities are exploring new solutions to improve the environmental and cost-efficiency of their waste management systems. Curitiba is a progressive city, known for its sustainability profile and tradition in innovative urban solutions. Curitiba is a member of the C40 group, a network of cities committed to reducing their environmental footprint (http://www.c40.org/about).

Biogas is a carbon-neutral, well-proven and versatile fuel both in terms of sources and uses. It can be produced through anaerobic digestion using sewage sludge, organic components of municipal solid waste, and residues from agriculture, forestry and food industries. Biogas can be used for cooking, power and/or heat generation, or be upgraded for use as vehicle fuel. Furthermore, the solid residue resulting from the biogas production process can be used as fertilizer, providing additional value for the plant (Al Seadi, et al., 2008).

Many cities are discovering biogas as a way to generate value from organic waste, reduce landfilled waste, and mitigate greenhouse gas emissions. In addition, biogas production could serve to reduce the costs of waste management, which is a major challenge in metropolitan areas where land for landfills can be difficult to find. However, it is important to make a good business case to attract investors and make biogas a replicable alternative. Conditions vary among cities, thus the business model for biogas production will have to be adjusted to fit the scale, local institutional arrangements, policy frameworks, and uses of the biogas.

OBJECTIVE

The objective of this study is to determine whether small-scale production of biogas from waste can be a profitable business proposition in Curitiba. We aim at quantifying possible revenue streams of biogas production and evaluate whether these would be enough to finance the investment and operation of a small-scale plant adjacent to one major source of organic waste in the city, the Mercado Regional. Could a business case be made, and who would be the most appropriate stakeholders to establish the biogas plant?

METHODOLOGY AND CONTRIBUTION

Qualitative data was collected through interviews and observations, and quantitative data was gathered from the literature and field study. Estimations to evaluate the business case were made based on-site specific conditions. We followed an inductive approach in relation to theory and empirical findings, adjusting the analyzed model to the conditions found on-site. We made estimations of annual revenues and costs to verify the viability of the investment in a small-scale plant. We then carried out a sensitivity analysis to identify factors that may pose risks to the prospective investment. The results led to recommendations for the city of Curitiba in relation to potential and opportunities do develop small-scale biogas production.

There are many commercially established technologies used for obtaining biogas from organic waste. We selected options that were considered realistic based on analysis of the literature and local conditions in Curitiba. We focused on the major revenues and costs in the plant, but excluded pre-treatment and distribution of the biogas from the quantitative analysis. Our study provides insight on production potentials in Curitiba, determining the feasibility of small-scale biogas plants. Our assumption is that the latter could become a model for the development of small and medium business in the metropolitan area. The results might also be applicable to other cities in Brazil, and other countries with similar conditions.

HOW MUCH ORGANIC WASTE IS AVAILABLE FOR A SMALL BIOGAS PLANT?

In the decentralized system considered, the substrate for anaerobic digestion is readily available on site. The substrate comes from clean streams of organic waste in Mercado Regional where fruits and vegetables are sold. It will have a very low level of contaminating substances, particularly if food merchants and employees are trained to separate the organic proportion of the waste in a container. A study conducted by Asquer et al. (2013) concluded that fruit and vegetable waste is suitable for anaerobic digestion, and does not require other substrates to improve the digestion. Gas yields will be around 72–74 m^3 per ton of fresh material.

The quantity of substrates locally available at Mercado Regional have been investigated by Pereira & Appel (2016). Using gravimetric studies, the authors found that 55 tons of organic waste are generated per year. In close proximity, we find the distribution center for Armazém da Família, which generates approximately 3 tons of organic waste per month. The latter can also be utilized for biogas production.

Using the organic fraction of waste for anaerobic digestion (AD) on-site reduces the costs of waste collection. The collection fee amounts to 90–95 R$/ton and the landfilling fee is 115–120 R$/ton for producers that exceed the limit stated in municipal contract. The fee for the regular door-to-door collection in Curitiba is at 65 R$/ton (Thá, 2017).

Small scale AD comprise digesters with a maximum treatment capacity of 7500 tons per year (Global Methane Initiative, 2016). These are often called household digesters as they are normally used by families or communities. Two main types to be considered are the fixed-dome plants and floating-drum plants. In addition, plug flow digesters are attracting increasing attention due to their portability and easy operation (Rajendran et al. 2012). As our substrate is mainly composed of fruits and vegetables, the floating-drum digester or a tubular digester are more appropriate than the fixed-dome digester. The latter has not been considered suitable for our type of substrate (Edelmann & Engeli 2015). Given the quantities and type of waste generated at Mercado Regional, with low content of TS (solids), the most likely process alternative is small scale wet digestion.

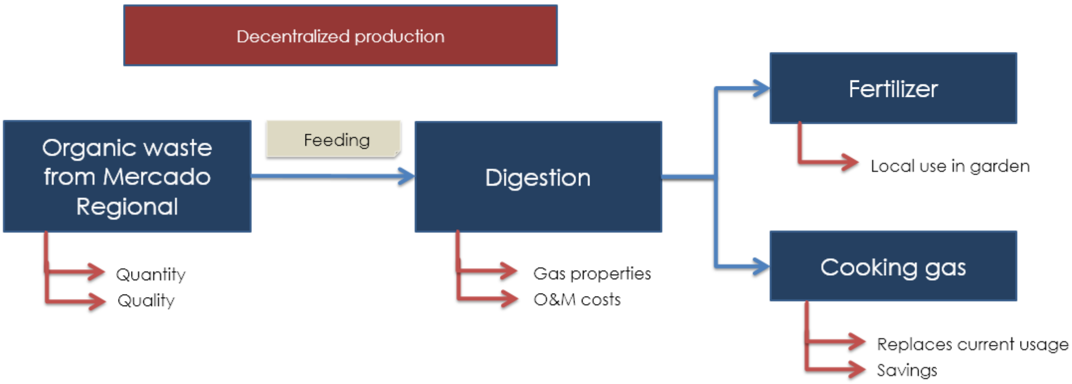
Small scale plants are normally built without heating but this can be added either through direct heating of the substrate mixture with steam or hot water, or indirect heating using heat exchangers on the floor, inside or outside the digester. Direct heating is more costly and seldom viable (Kossmann, et al., 1999). Since digester trials of unheated digesters have been unsuccessful in Curitiba due to climatic conditions (Makashima, 2017), external heating either in mesophilic or thermophilic conditions is advisable.

A hands on approach to calculate the digester size for a small scale wet digester is provided by Curry & Pillay (2011) and also used here. The equations for calculating HRT and OLR are indicated below. The cost for small scale digesters is not easily determined as they vary significantly between do-it-yourself (Dana, 2010) and professional technology, as well as in terms of labor requirements, material costs and local conditions. The investment costs for household scale digester technologies in rural areas of Latin America have been studied by Garfí et al. (2016) including the fixed-dome, floating-drum and tubular digesters. Pérez et al. (2014) analyzed costs for household digesters in rural Andean communities and found investment costs of $1 963 for a Chinese fixed dome for a volume of 10 m^3, and $1 729 for a Plastic tubular digester of the same volume. Both have a lifespan of 20 years, though the tubular digester requires substitution of plastic components every five years.

GENERATING BIOGAS AT MERCADO REGIONAL

We assume a daily volume of approximate 0.5 m^3 at Mercado Regional, with a waste density of 514kg/m^3. This requires a digester of 10 m^3 (Bouallagui et al. 2002). Calculations are performed to verify potential costs for digester technologies, and set the range for a digester size at Mercado Regional. Actual size and design might be different after a more precise feedstock analysis is performed. However, based on initial calculations, the household digesters offer suitable size alternatives for a plant at Mercado Regional.

To get an indication of the economic feasibility of biogas production at Mercado Regional, the potential of biogas production was estimated, followed by evaluation of possible revenue streams that can be obtained from a small-scale plant. This was used to assess the feasibility of the investment in a free cash flow analysis. The small scale decentralized production scenario is summarized below.



The feeding has a profound effect on the fermentation of the substrates, as sudden changes in the feeding can disturb the microbial balance. The optimal feeding is in small doses and homogenous mixes of substrates (Wellinger, et al., 2013). An important factor for modeling of the feeding is the Hydraulic Retention Time (HRT), which is the statistical average of time the feedstock spends in the digester (Busch, 2013). The HRT is calculated by the following formula (SEAI, 2017):

$$Hydraulic\ retention\ time[d] = \frac{capacity\ fermenter[m^3]}{fresh\ substrate\ added\ daily\left[\frac{m^3}{d}\right]}$$

Another important factor is the Organic Loading Rate (OLR), which is a measurement of the mass of organic dry matter that is fed into the reactor per unit of time and volume of the reactor. The unit for OLR is dry organic matter in kg per day divided by the capacity of the fermenter (Busch, 2013).

$$\text{organic loading rate}\left[\frac{kg\ VS}{m^3 d}\right] = \frac{\text{volatile solids added daily}\left[\frac{kg\ VS}{d}\right]}{\text{capacity fermenter}[m^3]}$$

We assume 8.5 tons/month of feedstock. This is the basis of all variable costs and income, linearly proportional to the waste flow. What changes is the impact that fixed costs and incomes have on the total net present value. The only income that is not proportional to waste flow is the amount saved on waste collection, since the amount collected is not the same as the amount produced. We calculate that, combined with waste from the food distribution center, some 11.5 tons could be available per month for biogas production.

The 8.5 tons/month result in a gas yield of approximately 73 m^3/ton, thus totaling 621 m^3/month. Methane content will be around 60-70% according to the literature. This gives a heating value in the range of 23.3 MJ/m^3 (Ludington, 2013). We assume a biogas density of 1.02 kg/m^3 based on the same interval for methane content mentioned before. Using densities for normal temperature and pressure, a density interval of 0.96–1.07 kg/m^3 is obtained (de Graaf & Fendler, 2010). LHV (lower heating value) of natural gas is 47 MJ/kg (GREET, 2010). The cost of natural gas is 280 R$/MWh. This is also the price paid at Mercado Regional through public procurement. The price of natural gas in Brazil has had a standard deviation of 16% during the last five years, and we used a similar price variation, which gives an interval of 3.09-4.27 R$/kg. Converted to price per energy content, this roughly equals 235–325 R$/MWh. According to a local consultant, the price range for waste collection and landfilling is quite stable within narrow intervals of 90–95 R$/ton for collection and 115–120 R$/ton for landfilling. Using the extremes of these ranges results in intervals of 205–215 R$/ton.

The amount of biogas produced monthly (621 m^3) is too small to justify an investment in electricity generation as it would give just over 1 MWh per month, with an average effect of under 2 kW and a 35% generator efficiency. However, the energy content is equal to that of almost 300 kg natural gas. This is roughly half the amount of gas that is currently bought for cooking at the market, which then could be replaced by the biogas.

In our scenario, the digestate is used for educational purposes only, and does not replace a current need. However, we have estimated the revenue potential in case the digestate is commercialized. The savings with waste collection and deposition are in the same order of magnitude as the savings from the replaced gas, while potential savings from substituted fertilizer would represent a smaller portion of the savings.

A sensitivity analysis indicated that the amount of waste flow and the gas price are the factors that affect the annual savings the most, while gas properties and waste collection cost are well-known and imply lower risk. Nevertheless, it seems that the annual savings should stay within 10% of the base case value with quite a high level of probability, providing a sound basis to justify further investigation of the business case.

CAN A BUSINESS CASE BE MADE?

Whether or not it is economically feasible to invest in a project like this depends on several factors. Since investment costs are difficult to estimate, we have chosen to treat them as a variable, determining what range of investment cost would be needed to achieve a positive net present value of the investment. We use the following equation to calculate the net present value of the investment:

$$NPV = \sum_{t=1}^{T} \frac{C_t}{(1+r)^t} - C_0$$

C_t=net cash inflow during period t
C_0=total initial investment costs
r=discount rate
t=number of time periods

Operation and maintenance costs are set at 12% of investment costs plus one month minimum salary annually (R$937) (TradingEconomics, 2017). These costs are the most uncertain factors, and depend largely on the chosen type of plant. We considered 100% loan for the facility, and interest rate at 11% according to

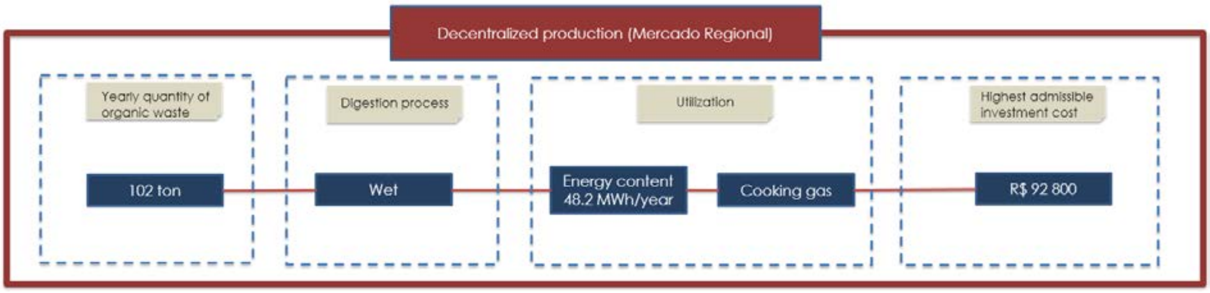
TradingEconomics (2017). In the sensitivity analysis, the interest rate was lowered to 7%, which is what could be obtained through subsidized loans, and raised to 15%, which is the highest it has been in the past few years. The cost of capital was adjusted accordingly while the debt-to-equity ratio was kept at 2. This resulted in a WACC (weighted average cost of capital) interval of 8.1–14.9% (Ross et al, 2013).

$$WACC = \frac{E}{V} * R_e + \frac{D}{V} * R_d * (1 - t_c)$$

R_e=cost of equity
R_d=cost of debt
E/V=percentage of financing that is equity
D/V=percentage of finance that is debt
t_c=corporate tax rate

Amortization time is set at 10 years (Probiogás, 2016) and depreciation time at 15 years which is reasonable based on existing literature. Solving this free cash flow model for investment cost by setting the net present value to zero results in a maximum investment cost of R$92,800. The prices cited by Garfí et al (2016) for digesters in the size range analyzed here vary between just under R$1 000 and R$6 000. The discrepancy in order of magnitude between the cost ceiling and the actual investment indicate that very large margins can be obtained from such a project. The highest price in the range gives a net present value of the investment of R$158 000. With such a margin for the admissible investment, the sensitive analysis becomes redundant. There is a clear business case here, which justifies further investigation.

CONCLUSIONS AND RECOMMENDATIONS



Case findings for a decentralized production of biogas at Mercado Regional

The results from the economic analysis for Mercado Regional are conclusively positive as the highest admissible investment costs may reach R$92 800, as compared to R$1 000–6 000 investment costs for a small-scale biogas plant as per estimated in other studies. The likely investment would render a NPV of R$158 000 for a period of 15 years and a capital cost of 20%. This gives strong evidence for a profitable business case for small scale biogas production in the vicinity of the market.

As the indications for profitability are so strong, there could be actors other than the municipality interested in developing the concept. However, the municipality may have to play a central role in breaking the initial barrier for the investment. At the moment, there are not many actors with knowledge of biogas in Brazil. A first demonstration may change that, and also have an important impact for establishing small-scale biogas production in Brazilian metropolitan areas. Once the concept is proven and operational guidelines are developed for small scale production, private companies could be interested in investing in similar projects.

The digester technologies found suitable for Mercado Regional were Floating-drum digesters and Tubular digesters due to the type of substrate intended for fermentation. Having local universities as partners in the venture could give such a plant a full demonstration purpose, allowing it to be a laboratory for tests on the feedstock, optimization, and education purposes, thus showcasing the solution and promoting its replicability. The plant can also be part of the municipality's plans to further develop its concept of waste management and connect it with other initiatives, i.e. for organic food production. A scalable and replicable version of small scale biogas production would create job opportunities in the construction and operation of digesters. Diversion of organic waste from the landfill and its use in anaerobic digestion reduces the global warming potential of the waste management system in the city and helps to achieve climate change mitigation goals.

REFERENCES

1. Al SEADI, T. et al., 2008. Biogas handbook. Esbjerg: University of Southern Denmark Esbjerg.
2. ASQUER, C., PISTIS, A. & SCANO, E.A., 2013. Characterization of fruit and vegetable wastes as a single substrate for the anaerobic digestion. Environmental Engineering and Management Journal, 12(S11), pp. 89-92.
3. BJÖRKLUND, S., ÖHMAN, N. 2017. Biogas opportunities in Curitiba – analysis of business potential for biogas production from municipal solid waste. KTH Royal Institute of Technology, master's thesis.
4. BOUALLAGUI, H., BEN CHEIKH, R., MAROUANI, L. & HAMDI, M., 2003. Mesophilic biogas production from fruit and vegetable waste in a tubular digester. Bioresource Technology, Volume 86, pp. 85-89.
5. BUSCH, G., 2013. Biogas technology. In: S. Yang, H. A. El-Enshasy & N. Thongchul, eds. Bioprocessing technologies in biorefinery for sustainable production of fuels, chemicals, and polymers. New Jersey: John Wiley & Sons, Inc., pp. 279-291.
6. CECCHI, F. et al., 2003. Characteristics of the OFMSW and behaviour of the anaerobic digestion process. In J. Mata-Alvarez, ed. Biomethanization of the organic fraction of municipal solid wastes. IWA Publishing, pp. 141-180.
7. CURRY, N. & PILLAY, P., 2011. Biogas prediction and design of a food waste to energy system for the urban environment. Renewable Energy, pp. 1-10.
8. DANA, R., 2010. Micro-Scale Biogas Production: A Beginners Guide, s.l.: Attra Sustainable Agriculture.
9. DE GRAAF & FENDLER, 2010. Biogas production in Germany, Dessau-Rosslau: Federal Environment Agency.
10. EDELMANN, W. & ENGELI, H., 2015. The arbi Plug-Flow Digester in Tanzania, Baar: arbi GmbH.
11. GARFÍ, M., MARTÍ-HERRERO, J., GARWOOD, A. & FERRER, I., 2016. Household anaerobic digesters for biogas production in Latin America: A review. Renewable and Sustainable Energy Reviews, Vol 60, pp. 599-614.
12. GLOBAL METHANE INITIATIVE, 2016. Overview of Anaerobic Digestion for Municipal Solid Waste, s.l.: s.n.
13. GREET, 2010. The Greenhouse Gases, Regulated Emissions, and Energy Use In Transportation Model, s.l.: Agronne National Laboratory.
14. INTERNATIONAL FINANCE CORPORATION, 2015. Curitiba Solid Waste Management - Project Booklet, s.l.s.n.
15. KOSSMANN, W. et al., 1999. Biogas - Application and Product Development, s.l.: GTZ.
16. LUDINGTON, D., 2013. http://masters.donntu.org. [Online] Available at: http://masters.donntu.org/2013/fkita/alexandrova/library/Heating_Value_of_Biogas_copy.pdf [Accessed 03 04 2013].
17. MAKASHIMA, M., 2017. [Interview] (19 04 2017).
18. PEREIRA, F.D. & DOS SANTOS APPEL, D.M., 2016. Gerenciamento de resísduos sólidos orgânicos dos Mercado Municipal e Regional de Curitiba: Diagnostico preliminar, Curitiba: Universidade Positivo.
19. RAJENDRAN, K., ASLANZADEH, S. & TAHERZADEH, M.J., 2012. Household Biogas Digesters—A Review. Energies, Volume 5, pp. 2911-2942.
20. Thá, D., 2017. [Interview] (24 04 2017)
21. PÉREZ, I., GARFÍ, M., CADENA, E. & FERRER, I., 2014. Technical, economic and environmental assessment of household biogas digesters for rural communities. Renewable Energy, Volume 62, pp. 313-318.
22. PROBIOGÁS, 2016. Barreiras e propostas de soluções - Para o mercado de biogás no Brasil, Brasília: Ministério das Cidades.
23. ROSS, S. A., WESTERFIELD, R. W. & JAFFE, J., 2013. Corporate Finance. 10 ed. s.l.:McGraw-Hill/Irwin.
24. SEAI, 2017. *seai.ie.* [Online] [Accessed 02 05 2017].Available at: http://www.seai.ie/Renewables/Bioenergy/Bioenergy_Technologies/Anaerobic_Digestion/The_Process_and_Techniques_of_Anaerobic_Digestion/How_to_calculate_the_retention_time_and_the_organic_loading_rate.pdfTRADINGECONOMICS, 2017. *tradingeconomics.com.* [Online] Available at: https://tradingeconomics.com/brazil/interest-rate [Accessed 05 05 2017]. Available at: https://tradingeconomics.com/brazil/minimum-wages [Accessed 18 05 2017].

25. WELLINGER, A., MURPHY, J. & BAXTER, D., 2013. The biogas handbook - Scinece, production and applications. s.l.:Woodhead Publishing Limited.