

Generating electricity during peak hours in Asuncion, Paraguay, through anaerobic digestion of cultivated water hyacinths

Generación de electricidad en horas de punta a partir de la digestión anaeróbica de camalote

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Abstract-- The objective of the present paper is to present an innovative and sustainable proposal for generating electricity in the metropolitan area of Asuncion, the capital of Paraguay, based on a renewable source of energy. Electricity would mainly be generated during peak hours with the aim of reducing power contracted by the Paraguayan Electricity Administration (ANDE) from existing hydroelectric power plants and thus reduce costs and stabilise transmission and distribution grids in the area of Asuncion. Electricity would be generated at a 130 MW combined cycle thermal power plant using biogas as fuel, this being obtained by anaerobic digestion of water hyacinths cultivated in pools, which would be built on the banks of the Paraguay river opposite Asuncion's botanical garden. The main advantage of using water hyacinths is their high growth rate, this being 100 to 500 g/day/m² depending on environmental conditions, thereby allowing plant mass to double every 6 to 15 days. Additionally, carbon to nitrogen ratio in water hyacinth vegetal mass is optimum for biogas generation. About 6.4 kWh/m³ biogas calorific value is high enough to be used for producing heat and, therefore, for generating electricity in a thermal power plant. Such power plant could be directly connected to the national grid through the Puerto Botanic transformer station by building a 2 km long 220 kV transmission line crossing the Paraguay River. This project could save ANDE up to 25 million US\$ every year due to reduced contracted power at the Itaipu power plant. Although this reduction will decline by 3% each year due to increased electricity demand, the investment of around 98 million US\$ could be repaid within 15 years and would have 5% IRR and US\$ 40.5 million NPV.

Keywords: water hyacinth, biogas, renewable energy,

electricity generation, peak hour, gas plant, grid stabilization.

Resumen – El presente trabajo tiene como objeto de presentar una propuesta novedosa y sustentable para la generación de energía eléctrica en el área metropolitana de Asunción basada en una fuente renovable de energía. Dicha generación se realizaría principalmente en horas de punta con el fin de reducir la potencia contratada por la ANDE en las usinas existentes y de esta forma disminuir costos y al mismo tiempo estabilizar las redes de transmisión y de distribución en la zona de Asunción. La electricidad se generaría en una planta térmica de ciclo combinado de 130 MW de potencia instalada utilizando como combustible biogás obtenido por medio de la digestión anaeróbica en biodigestores de plantas de camalote cultivadas en piletas a ser construidas en la orilla del río Paraguay frente al Jardín Botánico de Asunción. La principal ventaja para el aprovechamiento del camalote es su elevado índice de crecimiento, que es entre 100 y 500 g por día y por m² según las condiciones ambientales, lo que permite que se duplique su masa vegetal cada 6 a 15 días. La relación entre carbono y nitrógeno, que se encuentra en su masa vegetal es óptima para la generación de biogás, cuyo poder calorífico de unos 6,4 kWh/m³ es suficientemente elevado para utilizarlo para la generación de calor y por ende también de electricidad en una planta térmica. Esa usina podría conectarse directamente al SIN a través de la Estación de Puerto Botánico mediante una línea de transmisión en 220 kV de 2 km cruzando el río Paraguay. Mediante este proyecto la ANDE podría ahorrar por año hasta US\$ 25,000,000 en concepto de la contratación de potencia en la represa de Itaipú. Aunque dicho ahorro se reduciría cada año de 3% por el incremento de la demanda, la inversión de unos US\$ 98,000,000 podría ser amortizada en un plazo de 15 años y tendrá un TIR del 5% y un VAN de US\$ 40,548,000

Palabras clave: Camalote - Biogás - Energía renovable - Generación de electricidad - Hora de punta - Usina a gas - Estabilización de red.

1. INTRODUCTION

The electricity supply for the metropolitan area of Asuncion, the capital of Paraguay, mainly comes from the Itaipu hydroelectric plant. The Paraguayan Electricity Administration (ANDE) has to contract certain power from this bi-national entity which normally has to cover demand during peak hours. However, such contracted power is not used during most of the day, thereby signifying high costs for ANDE and electricity consumers. Electricity demand during

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summer time when temperatures are high causes overloads in the transmission and distribution grids due to the increasing use of air conditioners and, consequently, electricity supply cuts.

Both problems could be resolved if ANDE would dispose of one or various thermal power plants during peak hours, a solution which has already been proposed on several occasions by this entity. There are projects to install thermal power plants at several critical points around the country to stabilise the grid during peak hours during the summer. The problem of conventional thermal power plants is the use of fossil fuels (which are 100% imported), therefore costing a large amount in foreign currency and contribute to global warming. The present paper presents a more ecological and economical alternative to ANDE projects by using a renewable source of energy, i.e. biogas obtained by the anaerobic digestion of water hyacinths.

2. WATER HYACINTH

The water hyacinth (*Eichhornia crassipes*) is a water plant from the family *Pontederiaceae* which is native to tropical areas of South-America. This plant swims on the water surface with its roots hanging in the water without penetrating the ground (see Figure 1) and is very common in Paraguayan rivers, lagoons and swamps, but can be found throughout almost all of the world's tropical and subtropical regions. Originally it was introduced as an ornamental plant in garden pools, from where it then escaped. Nevertheless, due to its rapid growth and its easy adaptation to any aquatic ecosystem in many countries it has become a difficult to control pest. The only way to control its expansion is periodic harvesting which has led to the following ways of using the plant (Lindsey and Hirt, 1999):

- Protein-rich cattle fodder
- Organic fertiliser
- Raw material for paper and cardboard
- Raw material for rattan furniture and basketwork
- Solid fuel
- Green filter for wastewater treatment
- Biogas generation by anaerobic digestion

Water hyacinth growth rate is between 100 and 500 g/day/m² according to the actual environmental conditions (solar radiation, temperature, nutrient availability). So, 400 to 1,700 t of fresh material per year can be obtained per hectare, having 5% to 7% dry material content; the rest is water (Lindsey and Hirt, 1999).

Nevertheless, in Paraguay practically no use is made of water hyacinth plants, except maybe as fodder. It is more likely ignored and often even considered annoying, mainly regarding river navigation. This paper was thus specially focused on its potential use for generating biogas, which is relatively important due to its high protein content and can be

compared to the potential of pig or cattle manure. The carbon:nitrogen ratio for water hyacinth is 23 to 1, an ideal value for anaerobic digestion (Lindsey and Hirt, 1999).



Figure 1: Picture of a river colonised by water hyacinth (source: www.rios-galegos.com)

Water hyacinths are very effective as a green filter for removing many kinds of pollutants from wastewater, such as the following:

- Metal ions, i.e. copper, zinc, iron, quicksilver, chrome and calcium
- Residential wastewater
- Cattle manure
- Sugar mill residues
- Algae, suspended substances, composed odours
- Bacteria, yeast and viral substances
- Acids, alkalines and salts
- Organic components, including phenols
- Toxic substances, including pesticides

In ideal conditions, one hectare of water hyacinths can absorb nitrogen and phosphorus from the domestic wastewater produced by 800 people.

3. ANAEROBIC DIGESTION

Anaerobic digestion is a natural fermentation process which occurs in the total absence of oxygen by the action of various species of bacteria, resulting in stabilised organic matter and the production of a combustible gas, called biogas. Beside the absence of oxygen, other physical and chemical conditions have to be observed to enable anaerobic digestion in good conditions, such as pH (6.6 to 7.6), carbon/nitrogen ratio (15/1 to 45/1), temperature (15°C to 70°C), the absence of toxic substances, quantity of solids (10% to 40%) and retention time (up to 100 days) (Jarauta, 2005).

Biogas mainly contains methane (CH₄: 50% to 70%) and carbon dioxide (CO₂: 30% to 50%), beside small amounts (<1%) of hydrogen (H₂) and hydrogen sulphide (H₂S). The latter is a very corrosive substance which should be eliminated before using the gas to prevent corrosion of any metallic equipment with which it comes into contact.

The lower calorific value of biogas is about 6.4 kWh/m³.

Its value depends mainly on the percentage of methane contained in the biogas because carbon dioxide is an inert gas. Anaerobic digestion is always accompanied by a reduction of the substrates' organic content and the generation of gas. Installations specially designed to optimise this process are called biogas plants, biogas units or anaerobic digesters.

Anaerobic digestion is a very complex process in which several biochemical reactions occur (see Figure 2) which can be divided into three stages (hydrolysis, acidogenesis, methanogenesis). The molecules which compose the matter become smaller and smaller during the process and end up becoming converted into the different components of biogas. Characteristic bacteria mediate each stage and their population needs to have certain equilibrium. If, for example, there are too many bacteria in the second stage, the substrate will become acid, which can be observed by measuring the pH. This will inhibit the growth of methane producing bacteria and therefore gas production will become reduced.

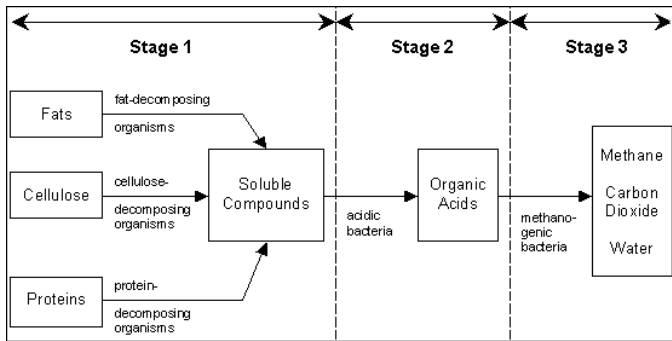


Figure 2: Stages of anaerobic digestion (source: www.daviddarling.info)

Temperature is a very important factor in anaerobic digestion. Three temperature ranges at which biodigesters can operate are usually distinguished; they differ regarding temperature and bacteria flora, this being specific for each temperature range. These ranges are:

- Psychrophilic: 10°C to 20°C
- Mesophilic: 20°C to 45°C
- Thermophilic: 45°C to 70°C

The most common range is mesophilic as its temperatures are close to ambient temperature in our climate. Each range has its optimal temperature, this being 37°C for the mesophilic range. The thermophilic range normally requires heating the substrate, thereby consuming part of the energy in the form of biogas. Nevertheless, it has the advantages that pathogenic bacteria are eventually destroyed and that organic matter decomposition is much quicker.

4. BIOGAS PRODUCTION FROM WATER HYACINTH

Water hyacinths have an optimum carbon / nitrogen ratio (C/N = 23) for anaerobic digestion (Lindsey and Hirt, 1999). Nitrogen comes from its protein components. On the other

hand, most fibrous plants, like grass, have an excess of carbon, thereby making their anaerobic digestion difficult. 300 to 400 l of biogas can be obtained from 1 kg of dry water hyacinth material (Lindsey and Hirt, 1999) a similar value to that for cattle manure. Yield would be about 500 l/kg in the thermophilic range. It should be added here that biogas supply would follow a similar curve to that for electricity demand during the year, both being dependant on ambient temperature. It also influences water hyacinth growth rate and biogas production, unless the digestors are equipped with heat exchangers using waste heat from a thermal plant. So, during summer when there is the highest electricity demand, there will also be the highest quantity of harvested water hyacinth and therefore maximum biogas production.



Fig. 3: Biodigesters at the San Bernardo Farm of Naranjal, Alto Paraná (Foto: Pulfer)

Within the framework of his MSc thesis Alvaro Maioli (mentored by Jean-Claude Pulfer, both being authors of this paper) is actually investigating the biogas yield obtained by anaerobic digestion of water hyacinths in different conditions. These data are very important for enabling the design of a project like the present one.

Enough biogas should be produced in the present proposal to make a combined 130 MW cycle thermal plant function for 3 hours a day. This power is enough to mainly cover the additional demand of electricity during peak hours in the metropolitan area of Asuncion. Considering a biogas yield of 500 l/kg of dry water hyacinth matter, 55% efficiency for the thermal power plant and a 6.4 kWh/m³ calorific value for the biogas are required to produce 110,000 m³ biogas per day. Considering an annual 100 t/ha dry water hyacinth matter production then about 800 ha of pools will be needed to cultivate this plant.

There is a floodplain in the riverside areas opposite the city of Asuncion, near the botanical garden, which is big enough to cultivate water hyacinths for this project. 2,000 pools should be built, each measuring 20 m wide, 200 m long and 0.8 m deep, separated from each other by a 4 m wide runway for the circulation of the harvesting machines. These pools will be filled with water from the Paraguay river. The water has to be renewed periodically to maintain a sufficient level of nutrients in the water for the plants' optimum growth and to compensate the water loss by evapotranspiration. The pools

will thus be interconnected with a network of tubes and channels connected to the river. A 5 km long defence dam will be built between the river and the installations to protect all these installations from floods during periods of rising water.

Water hyacinths will be removed and ground up by specially designed harvesting machines which will move along the runways between the pools. The ground plants will then be loaded into tank trucks which transport them to the digesters for unloading the substrate to be fermented. The 14 biodigesters consist of 20 m wide and 50 m long rectangular pools covered with waterproof ground cloth and another special cloth which collects the produced biogas like a balloon. Biodigesters of this type already exist in Paraguay, for example in Naranjal, in the Alto Parana Department, for treating pig manure at the San Bernardo farm (see Figure 3). Part of the waste heat generated by the thermal plant will be used to heat up the digesters, thereby enabling them to function in the thermophilic range, resulting in superior gas yield and lower retention time for the substrate than in the mesophilic range.

Once water hyacinth fermentation, lasting some 15 days, is concluded, the fermented organic matter temporarily flows into some special pools. The resulting product is an excellent organic fertiliser for agriculture; however, due to its very high water content, it would be better to dehydrate it before selling it.

5. THERMAL POWERPLANT

The proposed thermal power plant will be of the combined cycle type which consists of gas turbines and steam turbines, using part of the residual heat from the gas turbines. This type of thermal plant has the highest current energy efficiency (55% to 60%). The plant will be located close to the digesters to avoid having to transport the gas and will consist of two combined cycle turbines units having a total 65 MW power each and 70 MVA generators for each unit. Transformers will then raise the generated tension to 220 kV, which will allow the power plant to be connected to the national grid system (IEC, 60076). Such generator configuration enables ideal generated energy adaptation to its demand during peak hours following the demand curve as far as possible. Normally, only the gas turbines would be started first followed by the steam turbines according to need; the opposite procedure would be applied to reduce the generated power.

The location of the proposed power plant is quite close to the 220 kV Puerto Botanico transformer station; only a 2 km long 220 kV transmission line crossing the Paraguay river is needed to interconnect both installations (NBR, 5422).

6. IMPACT ON THE NATIONAL GRID SYSTEM

Two consumption peaks can clearly be observed taking into consideration the data for a typical Paraguayan grid

system load curve during a hot summer's day (see Figure 4). The first smaller amplitude peak occurs between 14:00 and 16:00 h and the second, more important one, between 21:00 and 24:00 h. reaching a maximum of almost 1,800 MW. These peaks are mainly due to an intensive use of air-conditioners. The minimum consumption during the early morning hours is only about 1,200 MW; this stresses the need for a power plant for peak hours.

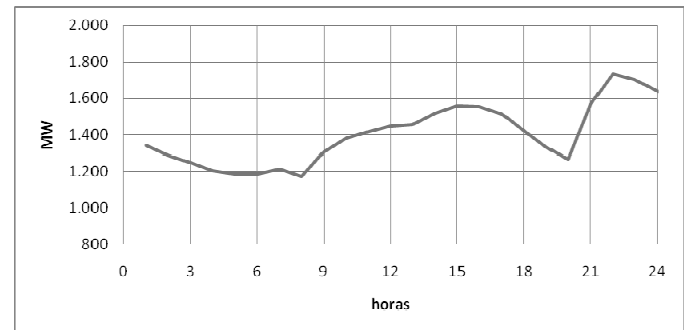


Figure 4: Typical load curve on a hot summer day in 2010 (source: ANDE)

The thermal power plant would then function during these peak hours, together with the Acaray hydroelectric plant totalling 340 MW power. The existing line from Puerto Botanico to the Parque Caballero transformer station can be used as a transmission line to down-town Asuncion, as it has enough capacity.

It should be born in mind that although the 500 kV transmission line between Itaipu and Villa Hayes (currently in the planning stage) will also considerably increase transmission capacity in all other tension levels (220, 66 and 23 kV), it will not solve the problem regarding consumption difference between peak and trough hours (ANDE, 2009-2018). This means that a power plant for peak hours is needed to reach a more balanced load factor. Another possible strategy would be that of promoting energy consumption during trough hours by offering special fees according to the timetable, for example electric cooking stoves or electro-intensive industries.

7. ECONOMICAL CONSIDERATIONS

An investment of about 98 million US\$ will be needed to implement this project. Considering a contribution by ANDE of some 13 million US\$ then external financing of around 85 million US\$ will be required. Also benefits granted by the Paraguayan law N° 60/1990 "About tax incentives on national and foreign investments" have been considered within investment needs; Beside, funds are available having very low interest rates and long repayment periods for this kind of renewable energy project. One example would be the Japanese government's loan to Paraguay for financing the Yguazu power plant. An annual 1% interest rate has been

considered for the present project and a 2-year amnesty period, the expected time taken for constructing the plant.

The economic approach in this case is that the investment will not be repaid by selling energy, but by the saving that ANDE will obtain from reducing the amount of power contracted at the Itaipu hydroelectric plant. This saving would reach an annual amount of around 25 million US\$ for the first year of operation. This amount would decrease 3% each year during the following years due to the increasing demand for electricity.

The investment could then be repaid in 15 years with a 5% IRR and 40.5 million US\$ NPV. Selling dried organic fertiliser at 10 US\$/t has also been considered as a source of income. As a renewable energy project, this scheme could benefit from the clean development mechanism (CDM) which would allow issuing and selling of carbon emission reduction (CER) certificates. An additional 2 million US\$ per year income could be obtained by considering as a base line a project with gas turbines having the same power using natural gas and a CER certificate price of 20 US\$/t (mean value in Europe).

8. OUTLOOK

The available space in the proposed site is big enough to increase the plant during a second phase; its capacity could practically be doubled by building another 2,000 pools for water hyacinths and all the other needed installations. Another possibility for increasing biogas production would be to incorporate waste water treatment into the plant's technology. The main outflow of untreated waste water from Asunción into the Paraguay river is located near the botanical gardens. An underwater tube would thus have to be built to cross the river where it will feed such a plant with waste water. The raw waste water would first pass through a decanting process. The sludge so obtained would then be treated by anaerobic digestion, like the water hyacinths.

The pre-treated waste water will then be sent to the oxidation pools containing water hyacinths, where the water will be cleaned. These water hyacinths will probably have an even higher growth rate than those in river water due to the water having higher nutrient concentration.

9. CONCLUSION

The present paper only represents a first feasibility study to demonstrate that it is technically and economically possible to install an environmental contamination-free thermal power plant close to the capital of Paraguay for peak hours, whose energy source is totally renewable and even locally produced. The economic benefit of such a plant in terms of savings on contracted power at Itaipu is considerable and would allow the investment to be repaid within a reasonable period. Another benefit would be the creation of a large number of jobs, not only during the building of the plant, but also during its operation. The proposal is totally innovative as, until now, no other project using a similar approach is known. From now on, this project's feasibility should be studied in depth, meaning that Alvaro Maioli's research will make an important contribution, mainly in knowing more about anaerobic water hyacinth digestion and biogas production from this plant.

10. REFERENCES

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