Economic feasibility of biomass gasification for small-scale electricity generation in Brazil

Guilherme P. M. Fracaro[1,*], S. N. M. Souza[1], M. Medeiros[1], D. F. Formentini[1], C. A. Marques[1]

[1] UNIOESTE (Universidade Estadual do Oeste do Paraná), Cascavel, Brazil
[*] Corresponding author. Tel: +55 4532248233, E-mail:guifracaro@yahoo.com.,br

Abstract: Although Brazil has a clean energy matrix, factors such as increased electricity consumption forecast for the next 25 years and the peculiarities of the isolated systems of electricity generation in the north of the country could require the inclusion of alternative energy sources that can show competitive production costs. This study aimed to evaluate the feasibility of a 100 kW_e gasification system including an engine generator set, examining the major costs in using this technology and the sensitivity of different factors on the variation of the electricity cost. With a capital cost of 1,100.50 €.kW_e^{-1}, the levelized unit cost of electricity delivered (LUCE) found was 459,83 €.MWh^{-1}, which would make this technology uncompetitive even in places where the generation is done using diesel oil. The parameters that showed to have a greater impact on LUCE were, in decreasing order, the load factor, the gasifier capital cost, the electric conversion efficiency, the capacity utilization factor and the gasifier useful lifetime, but even with variations of 30% within the range considered no parameter alone would allow reducing the LUCE to a competitive level.

Keywords: *Alternative energy sources, Biomass-based power plant, Levelized unit cost of electricity*

Nomenclature

E_O *annual delivered electricity output* . $kWh.y^{-1}$
P *rated power output* .... kWh
CUF *capacity utilization factor* ....fraction
α *generated power consumed by the auxiliaries* ....fraction
l *electricity losses in the local distribution network* ....fraction
AC *annual cost of BGPP* .... €.y^{-1}
R *capital recovery factor* ....fraction
c_d *diesel price* .... €.L^{-1}
c_b *biomass price*......................................€.kg^{-1}
sc_d *diesel specific consumption* .... $L.kWh^{-1}$
sc_b *biomass specific consumption* ....$kg.kWh^{-1}$
m_l *manpower wage*......................... €.$h^{-1}.man^{-1}$
d *discount rate* ....$fraction.y^{-1}$
LUCE *levelized unit cost of electricity*.. €.kWh^{-1}

1. Introduction

Biomass used in a sustainable way has a very important role to reduce the climate changes because it presents a carbon neutral balance, is relatively abundant and also because its forms of energy conversion have been already studied for a long time. Sustainable use of biomass can be defined as an infinite and continuous use which won't pollute and will maintain the natural resources and its benefits to humanity [1].

The energy conversion of biomass can be made by biological processes such as fermentation and digestion, by thermochemical processes such as combustion, pyrolysis and gasification, and also by mechanical extraction processes. Gasification can be defined as the conversion of biomass, or any solid fuel, into a gas fuel by partial oxidation at elevated temperatures [2]. The most common classification of types of gasifiers refers to the bed type, in the fixed bed gasifiers the biomass movement only occurs by gravity and in the fluidized bed gasifiers the fuel is kept in suspension by an intense oxidant medium flow, which can be air, oxygen or steam.

The produced gas has a combination of CO, CO_2, CH_4, H_2, N_2, tar, particulates and water, but its composition is extremely variable depending on the type and characteristics (texture, moisture, ash content and volatile compounds) of fuel used and the type and operating conditions (oxidant medium, temperature, pressure, etc.) of the gasifier [3]. For small-scale electricity generation, fixed bed downdraft gasifiers are generally more suitable due to lower tar levels in the produced gases [4].

Renewable sources, with the exception of hydropower, still have higher costs of electricity conversion [5], however, for small rural communities, their low levels of energy demand and high costs of transmission lines usually restrict the energy supply to these communities by connecting them to the conventional power grid, which can make the use of renewable sources in decentralized systems to become economically viable.

This paper aims to present an economic assessment of small-scale electricity generation from biomass gasification in Brazil. The technology considered for biomass energy conversion was a 100 kW_e downdraft fixed bed gasifier coupled to a diesel engine operation on dual-fuel mode.

2. Characteristics of the Brazilian electrical system

The Brazilian energy matrix can be considered “clean”, renewable sources are responsible for 48.7% of its primary energy [6], it has an installed capacity of 111 GW and nearly 80% of electricity produced in the country comes from a renewable source, 7% from biomass and 72% from hydropower [7], which makes the country's third biggest consumer of hydropower in the world, consuming 391 TWh in 2009 [8]. The country is currently experiencing a good economic period and it is expected an annual growth of 4.53% in electricity consumption for the next 25 years [9].

The Brazilian electrical system is formed by both the National Interconnected System (NIS) and the Isolated Systems (IS). NIS has a transmission network that sum 89,200 km and is responsible for 96.6% of the full capacity of electricity production in the country. The high costs of the national grid expansion in northern region of the country, due to its geographical characteristics and its low population density, makes the IS the major supplier of energy in this region. These systems cover an area equivalent to 45% of the national territory but they supply energy for only 3% of the population, with 8.7 TWh of electricity generated from fossil fuels in 2009. Despite the large subsidies FROM the government (about 1.05 billion Euros in 2007) [11], the average price of electricity paid by the customers in the Northern region is the country´s most expensive, 105 $€.MWh^{-1}$ [7], currently, some isolated communities in the Amazon region use diesel generators at an average generating cost ranging between 143 and 205 $€.MWh^{-1}$, whereas in the interconnected system the generating cost is around 22 $€.MWh^{-1}$ [12].

3. BGPP-based decentralized electricity generation

Decentralized systems are designed to meet the demands and needs of a small local population [13], often in areas previously without access to electricity. The use of biomass gasification for energy supply in this kind of community is a reality as demonstrated in countries such as India and China [14,15]. The most suitable technology for small-scale electricity generation (lower than $1MW_e$) through gasification processes is a downdraft fixed bed gasifier coupled to an internal combustion engine [17], because the gas produced into reactor is forced to pass through a high temperature throat, which produces a low tar content gas. Despite the fact that an ideal downdraft gasifier produces very low tar content gases, in practice the tar and particulates levels are still higher than the recommended levels, < 50 mg.Nm^{-3} and < 100 mg.Nm^{-3}, respectively [17]. consequently, it is necessary to use a gas cleaning system before feeding to an internal combustion engine.

the capacity utilization and the load factors of a rural village, where the demand for electricity is primarily for lighting, are commonly low and this lead to high electricity generation costs [21,24]. a low capacity utilization factor results in a underutilization of the biomass gasification power plant (BGPP) capacity. Furthermore, a low load factor has negative impacts on specific fuel consumption, and consequently in its conversion efficiency, and also in NOx and SOx emissions [19].

4. Economic feasibility

The economic feasibility of a BGPP is dependent on several factors, mainly the capital costs of the equipments (i.e. gasifier, engine-generator set, civil works and local distribution network), the specific fuel consumption, the capacity utilization factor (CUF) the useful lifetime of the equipments and fuel's prices. To assess the economic feasibility there are also several indicators, the most used are the levelized unit cost of electricity (LUCE) and the breakeven analysis values (e.g. the diesel price estimative or the distance of transmission lines under which the electricity generated by a BGPP becomes feasible), but also the Internal Rate of Return (IRR) and the Net Present Value (NPV) [17,20].

5. Methodology

Aiming to compare the financial results found in this study with other studies that considered different currencies, the values were converted to a common currency (Euro), considering the average of the quotations made in 2009 [23]. The conversion values are: 0.3608 (Brazilian Real), 0.7178 (American Dollar), 0.0148 (Indian Rupees) and 0.1046 (Chinese Yuan).

The non-monetary data that were needed to estimate the cost of electricity produced by the BGPP, as well as the methodology to calculate the LUCE were adopted based on the work of Nouni et al [21], this methodology is described below:

5.1. Levelized unit cost of electricity delivered output

The levelized unit cost of electricity (*LUCE*) delivered by BGPP, can be calculated as a function of the annualized cost of the BGPP and its amount of annual electricity delivered, as follows:

$$LUCE = \frac{AC}{E_O} \qquad (1)$$

Where AC is the annualized cost and E_O is the annual delivered electricity output of the BGPP with a rated power output (*P*) can be calculated by the following expression:

$$E_O = (P * LF) * (8760 * CUF) * (1-\alpha) * (1-l) \qquad (2)$$

Where *LF* represents the load factor of the BGPP, *CUF* is the capacity utilization factor, *α* is the fraction of generated power consumed by the auxiliaries of the BGPP and *l* is the losses in the local distribution network.

The annualized cost of the BGPP (*AC*) has been calculated as follows:

$$AC = FC + VC \quad (3)$$

Where *FC* and *VC* represent the fixed and variable costs of the BGPP, respectively.
The *FC* are the costs that doesn't vary with the BGPP productivity, they can be estimated using Eq. (04):

$$FC = AC_g + AC_{eg} + AC_{cw} + AC_{ldn} \quad (4)$$

Where *AC* represents the annualized capital cost of each item of the power plant, they are the gasifier (*g*), engine-generator set (*eg*), civil works (*cw*) and the local distribution network (*ldn*), they can be calculated according to their capital costs (C) and capital recovery factors (*R*), which is a function of the discount rate (*d*) established. The equation to obtain *R* is described below:

$$R = \frac{d(1+d)^T}{(1+d)^T - 1} \quad (5)$$

Where *T* is the useful life time of each item of the power plant. The *AC's* were obtained according to Eq. (06), described below:

$$AC_x = C_x * R_x \quad (6)$$

The *VC* represent the costs that vary according to BGPP productivity, as follows:

$$VC = AC_{O\&M} + AC_F \quad (7)$$

Where $AC_{O\&M}$ are the annual operation and maintenance costs of each item of the BGPP, and AC_F are the annual costs with fuel, calculated as follows:

$$AC_{O\&M} = C_g * m_g + C_{eg} * m_{eg} + C_{cw} * m_{cw} + 8760 * C * m_l * n \quad (8)$$

Where m_g, m_{eg} and m_{cw} represent the fraction of the capital cost of each item of the BGPP that is necessary to its operation and maintenance, m_l is the Brazilian manpower wage rate and *n* is the manpower required.

$$AC_F = 8760 * C * CF * (c_d * sc_d + c_b * sc_b) \quad (9)$$

Where c_d and c_b are respectively the local prices of diesel and biomass, sc_d and sc_b are the specific consumption of diesel and biomass in the power plant.

5.2. Simplifications and assumptions explanation

Table 1 shows all the values that were utilized to estimate the electricity generated cost of the BGPP:

5.2.1. Capital costs

The capital costs of equipments (i.e. the gasifier and the engine-generator set) were established with the intention of reflecting the reality of the Brazilian market. For this, it was made quotes from some of the industries that produce these equipments in a commercial scale, however, currently Brazil has only one company producing gasifiers in a commercial scale and the capital cost of the gasifier was obtained from this company. It refers to a 500 kW_{th} fixed bed downdraft gasifier including the additional costs with auxiliary systems (e.g. an automatic feeding system, two cyclones, a fabric filter and a gas cooling system) and transportation, resulting in a capital cost of € 70,350.00. The established capital cost for a 100 kW_e diesel engine-generator set adapted to operate on dual fuel mode represents an average cost of € 32,500.00. The civil works cost were estimated at € 7,200.00, the amount is related to a facility with 50 m² at a average specific cost of 144 €.m⁻². the capital cost of the local distribution network was estimated based on an average value obtained from a local energy company, called COPEL.

Table 1. Parameters values to LUCE calculation.

Parameter	Unity	Value
Power rated capacity of BGPP	kW_e	100
Capital cost of gasifier	€	70,350.00
Capital cost of engine-generator	€	32,500.00
Capital cost of civil works	€	7,200.00
Specific capital cost of local distribution network	$€.km^{-1}$	5,000.00
Size of local distribution network	*km*	3
Price of biomass	$€.kg^{-1}$	0.0180
Price of diesel	$€.L^{-1}$	0.7190
Specific consumption of biomass (referred to the electric output)	$kg.kWh^{-1}$	1.21
Specific consumption of diesel (referred to the electric output)	$L.kWh^{-1}$	0.10
Capacity utilization factor	%	25
Load factor (function of BGPP's rated capacity)	%	75
Generated power consumed by BGPP	%	10
Electrical losses in local distribution network	%	10
Discount rate	%	10
Useful lifetime of gasifier	*h*	10,000
Useful lifetime of engine-generator	*h*	20,000
Useful lifetime of civil works	*y*	20
Useful lifetime of local distribution network	*y*	20
Manpower required by BGPP	-	2
Brazilian's manpower wage	$€.man^{-1}.h^{-1}$	2.35
Maintenance cost of gasifier (function of its capital cost)	%	5
Maintenance cost of engine-generator (function of its capital cost)	%	10
Maintenance cost of civil works (function of its capital cost)	%	2
Northern Brazil's reference tariff	$€.MWh^{-1}$	105
Isolated systems reference tariff	$€.MWh^{-1}$	174

5.2.2. Brazilian's manpower wage

The forecast labor cost was calculated based on the Brazilian minimum wage, equal to about € 186 a month, with an additional of 104% related to the charges applied.

5.2.3. Specific fuel consumptions

Based on current market price, it was stipulated the value of 18 $€.t^{-1}$ for prepared wood. The value of 0.7190 $€.L^{-1}$ for diesel based on the average prices paid in 2008 by the Isolated Systems power plants [22].

6. Results

6.1. BGPP's capital cost

The BGPP's capital costs found in this study were 703.5 $€.kW_e^{-1}$ to gasifier, 325 $€.kW_e^{-1}$ to engine-generator set and 1100.50 $€.kW_e^{-1}$ to the power plant. These values don't differ much from the values presented by Nogueira and Lora [24] WHO stipulated 861.36 €.kW$_e^{-1}$ as a reference to power plants using gasifiers coupled to internal combustion engines. Liu et al [25] quoted a value around 1046 €.kW$_e^{-1}$ as the capital cost of a BGPP in China. Due to several factors involved in setting the capital cost of a BGPP (mainly the scale of the project and the technologies considered) can also be found values with greater discrepancy [26,27].

6.2. BGPP's annualized costs

Figure 1 shows the extent of the impact of the studied costs on the LUCE. The annualized capital cost proved to be the main factor impacting the BGPP annualized cost (approximately 47% of the total) out of which 33% are due to the gasifier capital cost. Expenditures with labor and diesel proved to be almost equivalent, around 17% and 19% respectively. Although several authors cite that the diesel can be responsible for less than 30% of the energy produced by an engine-generator set operating on dual fuel mode [15,19,27,28] the spending with this fuel has represented more than 3 times the spending with biomass, this occurs due to much higher diesel specific cost compared to the cost of biomass.

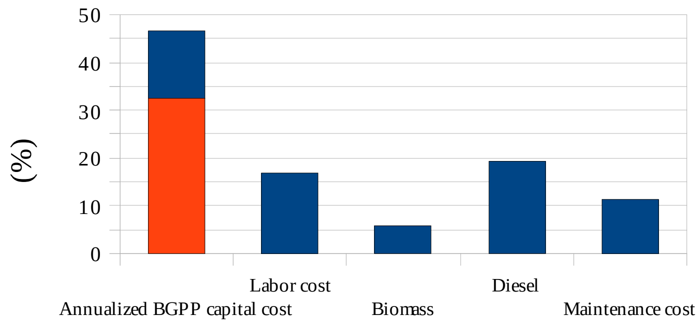

Fig. 1. Different costs responsibilities in BGPP annualized cost.

6.3. Delivered electricity cost

The estimated cost of electricity delivered by the BGPP under the established conditions was 459.83 €.MWh^{-1}, which represents approximately 4.38 times the price of the electricity paid by the customers in the Northern region of the country. Even when the comparison is based on the average price of electricity produced by diesel engine-generator sets in the Isolated Systems, the established luce showed no economic feasibility to an investment in a BGPP with these characteristics (264% of the isolated systems reference tariff).

6.4. Sensitivity analysis

As shown in Figure 2, the load factor is the parameter whose variation has greatest impact on the LUCE, if the BGPP operates at its rated capacity, the LUCE would be reduced to 380.41 €.MWh^{-1}, kept constant all the other factors. This reduction has even greater potential because the performance of both gasifier and engine-generator set tend to increase at higher load factors [19,21]. Also factor with important impact on LUCE were the electric conversion efficiency, the CUF and the gasifier useful lifetime, which with a 30% increase in their values could have respectively 7.5, 6 and 6% in LUCE reduction. Furthermore, a 30% reduction in gasifier capital cost could represent a 11.5% reduction in LUCE.

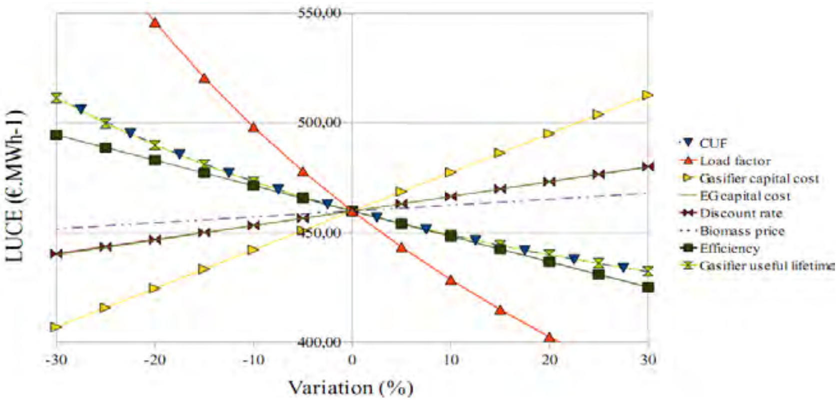

Fig. 2. Sensitivity analysis of BGPP.

7. Conclusions

It IS concluded that, under the studied conditions, the biomass gasification technology is still economically unfeasible to small-scale electricity generation in Brazil.

The main costs involved in BGPP electricity production, in descending order, were: the annualized capital costs (mainly the gasifier annualized capital cost), diesel, labor, maintenance and biomass costs.

In an attempt to reduce the LUCE of this BGPP, the load factor was the parameter that showed a higher sensitivity to reach this goal, followed by the gasifier capital cost, the electric conversion efficiency, the capacity utilization factor and the gasifier useful lifetime. however, with a variation of ±30% in the values previously established none of these factors would have a sufficient impact in LUCE to make this BGPP economically competitive in the Brazilian energy market. Even with a 30% variation of all factors at the same time (a 30% increase to the cuf, load factor, efficiency and gasifier useful lifetime and a 30% reduction of the gasifier and eg capital costs, discount rate and biomass price) the LUCE would be equal to 232.95 Euros. This value is still higher than the isolated systems reference tariff.

References

[1] L.Reijnders, Conditions for the sustainability of biomass based fuel use, Energy Policy 34, 2006, pp. 863–876

[2] P.Mckendry, Energy production from biomass (part 2): conversion technologies, Bioresource Technology 83, 2002, pp. 47-54

[3] P.Mckendry, Energy production from biomass (part 3): gasification technologies, Bioresource Technology 83, 2002, pp. 55-63

[4] A.F. Kirkels, G.P.J. Verbong, Biomass gasification: Still promising? A 30-year global overview, Renewable and Sustainable Energy Reviews 15, 2011, pp. 471-481

[5] D.Popp, I.Hascic, N.Medhi, Technology and the diffusion of renewable energy, Energy Economics, In Press, Corrected Proof, Available online 7 September 2010

[6] MME – Ministry of Mines and Energy/EPE – Energy Research Company, National Energy Balance, 2008

[7] ANEEL – National Electric Energy Agency website: www.aneel.gov.br

[8] BP Statistical Review of World Energy, June 2010

[9] MME – Ministry of Mines and Energy/EPE – Energy Research Company, National Energy Matrix 2030, 2007

[10] A.C.A. Costa, N.P. Junior, D.A.G. Aranda, The situation of biofuels in Brazil: New generation technologies, Renewable and Sustainable Energy Reviews 14, 2010, pp. 3041-3049

[11] ANEEL – National Electric Energy Agency, Atlas of electricity power in Brazil, 3rd Edition, 2008

[12] E.S. Lora, R.V. Andrade, Biomass as energy source in Brazil, Renewable and Sustainable Energy Reviews 13, 2009, pp. 777-788

[13] D.P. Kaundinya, P. Balachandra, N.H. Ravindranath, Grid-connected versus stand-alone energy systems for decentralized power – A review of literature, Renewable and Sustainable Energy Reviews 13, 2009, pp. 2041-2050

[14] C.Z. Wu, H. Huang, S.P. Zheng, X.L. Yin, An economic analysis of biomass gasification and power generation in China, Bioresource Technology 83, 2002, pp. 65-70

[15] B. Buragohain, P. Mahanta, V.S. Moholkar, Biomass gasification for decentralized power generation: The Indian perspective, Renewable and Sustainable Energy Reviews 14, 2010, pp. 73-92

[16] E. Alakangas, M. Flyktman, Biomass CHP technologies, VTT Energy Reports 7, 2001

[17] P. Hasler, T. Nussbaumer, Gas cleaning for IC engine applications from fixed bed biomass gasification, Biomass and Bioenergy 16, 1999, pp. 385-395

[18] M.R. Nouni, S.C. Mullick, T.C. Kandpal, Providing electricity access to remote areas in India: An approach towards identifying potential areas for decentralized electricity supply, Renewable and Sustainable Energy Reviews 12, 2008, pp. 1187-1220

[19] R. Uma, T.C. Kandpal, V.V.N. Kishore, Emission characteristics of an electricity generation system in diesel alone and dual fuel modes, Biomass and Bioenergy 27, 2004, pp. 195-203

[20] F. Goor, J.-M. Jossart, J.F. Ledent, ECOP: and economic model to assess the willow short rotation coppice global profitability in a case of small scale gasification pathway in Belgium, Environmental Modelling & Software 15, 2000, pp. 279-292

[21] M.R. Nouni, S.C. Mullick, T.C. Kandpal, Biomass gasifier projects for decentralized power supply in India: A financial evaluation, Energy Policy 35, 2007, pp. 1373-1385

[22] ELETROBRÁS, Anual plan for fuels – Isolated sytems, 2009

[23] Central Bank of Brazil website: www.bcb.gov.br

[24] L.A.H. Nogueira, E.E.S. Lora, Dendroenergia: fundamentos e aplicações, Interciência, 2nd edition, 2003

[25] T. Liu, G. Xu, P. Cai, L. Tian, Q. Huang, Development forecast of renewable energy power generation in China and its influence on the GHG control strategy of the country, Renewable Energy 36, 2011, pp. 1284-1292

[26] T. Buchholz, I. Da Silva, Potential of distributed wood-based biopower systems serving basic electricity needs in rural Uganda, Energy for Sustainable Development 14, 2010, pp. 56-61

[27] D. Brown, M. Gassner, T. Fuchino, F. Maréchal, Thermo-economic analysis for the optimal conceptual design of biomass gasification energy conversion systems, Applied Thermal Engineering 29, 2009, pp. 2137-2152

[28] N. Tippayawong, A. Promwungkwa, P. Rerkkriangkrai, Durability of a small agricultural engine on biogas/diesel dual fuel operation, Iranian Journal of Science & Technology 34, 2010, pp. 167-177