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WOOD GASIFICATION ENERGY MICRO-GENERATION SYSTEM IN BRAZIL- A MONTE CARLO VIABILITY SIMULATION

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ABSTRACT

The penetration of renewable energy into the electricity supply in Brazil is high, one of the highest in the World. Centralized hydroelectric generation is the main source of energy, followed by biomass and wind. Surprisingly, mini and micro-generation are negligible, with less than 2,000 connections to the national grid. In 2015, a new regulatory framework was put in place to change this situation. In the agricultural sector, the framework was complemented by the offer of low interest rate loans to in-farm renewable generation. Brazil proposed to more than double its area of planted forests as part of its INDC- Intended Nationally Determined Contributions to the UNFCCC-U.N. Framework Convention on Climate Change (UNFCCC). This is an ambitious target which will be achieved only if forests are attractive to farmers. Therefore, this paper analyses whether planting forests for in-farm energy generation with a with a woodchip gasifier is economically viable for microgeneration under the new framework and at if they could be an economic driver for forest plantation. At first, a static case was analyzed with data from Eucalyptus plantations in five farms. Then, a broader analysis developed with the use of Monte Carlo technique. Planting short rotation forests to generate energy could be a viable alternative and the low interest loans contribute to that.

There are some barriers to such systems such as the inexistence of a mature market for small scale equipment and of a reference network of good practices and examples.

Keywords: Biomass, distributed generation, small-scale, Monte Carlo

1. INTRODUCTION

In the early 80´s, Alvin Toffler, an American philosopher and futurologist created the term “prosumer” to describe a mass movement of people who would participate in the production process, both for the pleasure of building their own products or as part of their economic life (TOFLER; ALVIN, 1981).

At that time, the “do it yourself” movement and personal computers were gaining momentum. For (KOTLER, 1986) came back to the same theme and discussed the implications of the prosumer to marketing. He classified prosumers in two main groups “The avid Hobbyist”, including those who spend most of their free time doing something else in an intense way, and “The Arch prosumer”, those who want to be closer to nature and do things by themselves and whose motto was “small is beautiful”.

They had no idea that years later their concept would apply perfectly to the electric power sector and impact the way electricity generation and distribution were organized. With the development of distributed renewable energy, especially solar photovoltaics, and the possibility of connecting generators to the grid, millions of people started to use and sell energy. This new paradigm changed completely cost relations, presented challenges to grid management and opportunities for new innovative businesses (PARAGAND; SOVACOOL, 2016).

The expansion of prosumers and distributed renewable energy is not homogeneous in the world, due to different conditions of countries in the world (CRIEKEMANS, 2012).

BRAZIL has 4.3 million family run small-scale rural properties (family farmers). They represent 84% of rural properties in number and cover 25% of Brazilian farm land. Property size varies between 1 ha up to 100 ha (MDA, 2016) and a good proportion of the reforestation effort to achieve the INDC reforestation target is expected to be in these areas.

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A concessional credit line with interest rates of 2.5% and 12-year pay-back, exclusive to family farmers and renewable energy generation, was created by the National Program of Family Farming Promotion (PRONAF).

This is the best financial loan available in the country for electricity generation (MDA, 2016) and the key question is whether it can enable the reforestation of set-aside areas with short rotation trees and the production of decentralized electricity by family farmers. In case of a positive answer, funding and need of legal compliance could work as an induction engine and the Brazilian INDC would progress simultaneously in two fronts. However, setting up an energy system requires matching resource availability with suitable technology.

One of the technological alternatives of small scale processing of forest biomass for power generation is gasification of wood chips associated with the use of internal combustion engines, two well-known technologies. At larger scales, gasification is cost competitive with combustion and is more efficient) (BRIDGWATER et al ,2012) but various authors stress that the cost of small scale-plants could be a limiting factor to commercial operation, with specific capital costs above US$10,000/kW (BOCCI, 2014; LEE, 2013).

On the other hand, combustion equipment for electricity generation are large and not appropriate to farm-level production. In the last few years, a series of small-scale gasifiers with integrated generators and inverters entered the global market (BLANCHARD, 2015) and offer machines in the range of US$ 1500-3000/kW.

The aim of this paper is to analyses the technical and economic feasibility of a simulated small-scale grid connected electricity generation system in which small-scale farmers plant forests and generate electricity through gasification of wood chips within farm boundaries, in face of the current legislation and concessional incentives for small in-farm renewable energy generation, with two levels of analysis:

- A specific case study with defined species, forest costs and production was used to determine the role of different variables and technological barriers of the system and its components;
- The risk of adoption of similar concept in South, Southeast and Central Brazil were production, costs and material preparation may vary in a stochastic way.

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2. MATERIAL AND METHODS

A mix of 3 different commercial clones of Eucalyptus grandis, E. urophylla and E. urograndis (A08, G100 and I144) was planted in in 5 different small-scale family neighbouring farms, located at Ajuricaba Condominium, Marechal Cândido Rondon, Brazil (central coordinate of farms: 24o36´S, 54o08´W). The forests were planted by farmers and the International Centre on Renewable Energy – Biogas (CIBIOGAS), a research and development institute associated to Itaipu Binational (an energy company owned by Brazil and Paraguay), guided the establishment of forests, accounted costs and measured height and diameter of all trees at 3 years old in the area.

Using SisEucalipto simulator, developed by Embrapa (OLIVEIRA et al, 2014) the yield in volume of plantations was calculated to each farm for two different plant densities (3333 plants per hectare in a 1x3m spacing and 1667 plants per hectare in a 3x2 spacing), 2 rotations of 5 and 6 years, 95% of survival of plant Prices at the local were collected by CIBIOGAS.

Other prices were supplied upon consultation to the Secretariat of Agriculture of Paraná, associations of producers, Forest Institute of Paraná, farmers and agricultural cooperatives.

Simulations considered Electrical Capacity Factors varying from 0.55 to 0.7 (3942-6132h of generation per year). As the loan of PRONAF is payable in 12 years, the analysis was based on a 12-year discounted cash flow, with Net Present Value (NPV) being used as the dependent variable and measure of potential success of the business. A sensibility analysis of each of the input variables described below was also done. s in the first year. Labour was accrued by CIBIOGAS at US$2.75/hour, the regional value of general services, even when tasks were carried out by the farmer.

LCOE (Levelized Cost of Energy) was calculated and compared with photovoltaic energy using the methodology described in Blanchard (2015) for a period of 20 years.

The Monte Carlo simulation, a technique that allows analyzing risk in uncertain environments, without the construction of complexes equations to model a situation. The method consists of analyzing the effect of simultaneous variation of

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input variables in a dependent output variable by random sampling values within the variability distribution of each input variables with a very large number of interactions, so that after a distribution of probabilities of occurrence can be determined.

In fact, it performs an aggregation of many "what if" simulations and presents the distribution of all possible results (FRAUNHOEFER, 2013; REES, 2015) interactions were done with random sampling of electrical capacity factor, cost of feedstock, price of sale of energy (with an expected value 10% below consumer price from national utility companies), specific cost of generator and value of extra heat generated (as a surplus of heat generation, not used to dry chips), the independent variables which influence net present value (NPV) of the business.

A triangular distribution was used for all independent variables as their actual distribution is not known. According to HUANG et al (2015) this is a reasonable assumption. Minimum, maximum and most probable values for each variable were estimated as described above.

The software @Risk 7.50 from Palisade Corporation was used in association with Microsoft Excel.

3. RESULTS AND DISCUSSION

3.1. Forest Production

As the cost per hectare in all five Ajuricaba Condominium was the same, it is clear that areas with better growth present a lower cost per ton of wood. Although small-scale farmers seldom pay land lease, the inclusion of cost of land in calculations is common and an annual land lease of US$100 was considered as a cost of opportunity of land. Cost of production of an odt varied from US$8.00 to US$29.00, with an average of US$13.00.

According to a recent survey, 1 million hectares of forest plantations exist in the State of Paraná, half in the hands of large forest companies and the other half in farmers-land HUANG et al (2015). Both methods suggested in this study are viable, though there are few or no service providers or experience in drying wood chips in small-scale in Brazil.

The two methods are: Acquisition of a combined heat module sold by the manufacturer for US$5,000, with a capacity of 20 kWh when operating at 18kWe,

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plus US$500 for a heat exchanger and a fan for air circulation through the pile. The latent heat of evaporation of water is 686 kWh/t and 0,9kg must be evaporated for every kWh generated (reducing moisture content from 100% to 25%), the CHP would generate twice the required heat.

Felling and stacking the wood 3 months before chipping, so that wood moisture content drops to 40%, followed by chipping and then drying, according to the suggestion of the technical assistance of the gasifier manufacturer, by of sun-drying the feedstock in canvasses, and if further drying is required using a forced-air flow from the hot air that gets blown out of the radiator on the engine. The advantage of this method is that, apart from labor costs, no further investment is required. The disadvantage is that the method is unreliable in rainy seasons and the feedstock drying process may be disrupted. The cost of drying, independent of the strategy, was estimated in US$9/odt.

3.2. The Integrated System

Integrating forest production and generation of electricity is a challenge in terms of dimensions, planning and logistics. As generator, can operate at different capacity factors (CF) it will demand different quantities of fuel. At a 0.45 CF, the generator would operate 3942 hours and require 85t of wood dry wood per year. At 0.7, it would operate 6132 hours and require 132t. This increased fuel consumption has a consequence on the area of forests that will be annually harvested.

As the production of feedstock starts 5 years before any increase in capacity factor a grade of long term planning is involved in the activity. If there is no forest to supply the generator, it either stops or must be run with wood purchased from the market at high prices. Even if the forest supply is not a limitation, as capacity factor increases, the logistics of harvesting, chipping, drying and storing wood also increases.

Most probably, a single small farm will not consume all energy generated at this scale. Therefore, businesses like that would only work with a group of small farmers consuming the energy or if partners participate with capital and benefit from reduced energy rates. In that case, the owner of the forest and the gasifier would work as a small energy company and the off-farm partner as a client.

3.3. Economic and Risk Analysis

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The Local Case Scenario

If an average farmer at the Ajuricaba Condominium sets a business under the conditions presented in Table 1, he would have to invest US$ 51,800 and, after 12 years, the NPV of his business would be -US$51,800. Therefore, in this situation, gasification is not viable.

TABLE 1: Conditions For The Local Case Average Farmer At The Condominium Ajuricaba

Electricity capacity factor	0.55	Specific Capital Cost ($/kWe)	2,600
Generator electrical output power (kWe)	18	On-site electricity value ($/kWh) = grid price	0.20
Generator heat output power (kWTh)	20	On-site heat tariff ($/kWh)	0.1
Fuel consumption (kg/kWhe)	1.2	Heat utilization factor	50%
Discount rate (%)	5.0	Annual labour cost for operation (US$)	3,000
Yearly operational cost of generator (% of cost of generator)	5.0	Period of business (years)	12
Cost of a shed to storage and generator	5,000	Land rent embedded in feedstock cost (US$/year)	100
MAI (odt/year)	26	Feedstock cost ($/odt)	46
Regional price of wood chips ($/odt)	70-80	Minimum estimated cost of feedstock ($/odt)	30

When a sensibility analysis is carried out with the main variables considered as seen of Fig. 1, electricity value is the variable of higher impact, but as the value considered was equal to grid price and there is no sense in raising it above grid price, it is not under farmer´s control. The same happens with specific capital cost, which is set by the market and cannot be changed by the farmer.

Again, the value considered in the initial analysis was the same as the sales price in US, which does not consider freight, taxes etc., and actual prices at the Brazilian market are likely to be higher. Annual payroll and heat value have little influence on the business, and therefore electrical capacity factor (CF) and fuel cost are the two variables under control of farmers that could increase attractively of the business.

At a CF of 0.55, the cost of wood chips would have to be lower than US$ 10/odt to generate profit, but simulations show that the lowest possible cost of chips would be US$30/odt. In fact, if everything is kept with values presented at Table 1 and the CF is increased to 0.62, the NPV turns positive and the business would

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become attractive. If the specific cost of the equipment is increased to US$3,000/kWh, a more likely value of equipment with freight and tax exemption, a Capacity Factor of 0.70 would be required to turn the investment attractive with that fuel cost.

The main incentive given by the Brazilian government to promote the adoption of renewable energy systems is the PRONAF loan with interest rate of 2.5% per year, 3 years of grace and 12 years to pay. With the loan, farmers do not have to disburse money upfront and all investment in the generator is paid in instalments after the 3rd year. That changes completely the cash flow of the business (Fig. 1).

At the initial condition of a capacity factor of 0.55, the generation would pay the loan and yearly operational profit would be bordering zero after the third year. With the specific cost of the generator at US$ 3,000, the generator would have to run at a 0.6 capacity factor to avoid annual operational deficit.

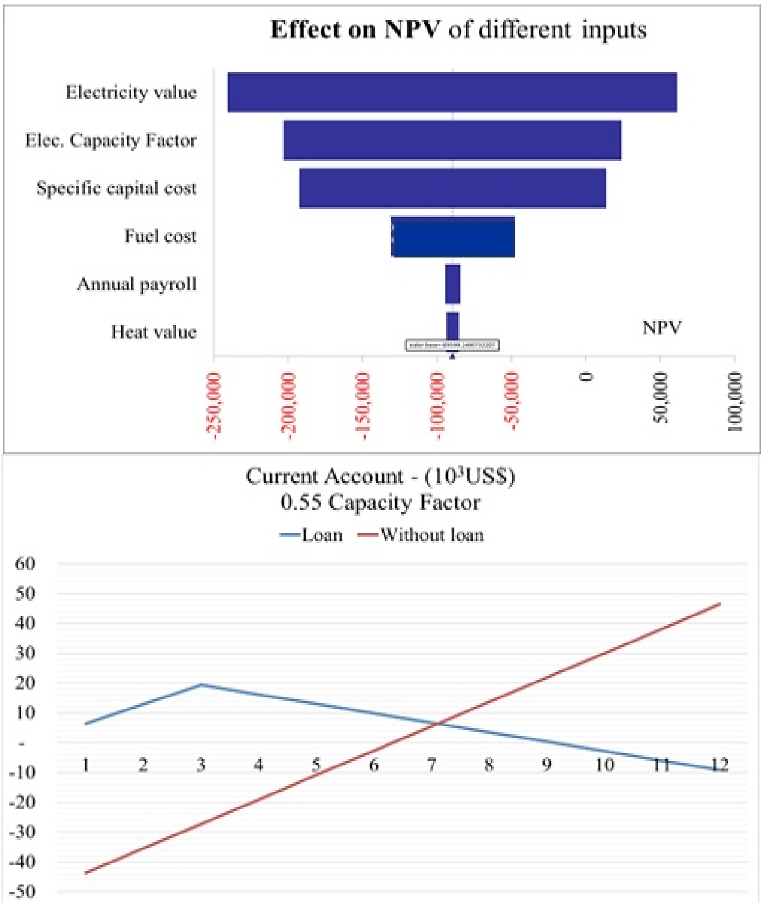

Figure 1: Sensibility Analysis and Effect of Loan on Current Account

Running an equipment 60% of the time is equivalent to operate it 14.4 hours a day every day or 18.8 hours a day if it is operated 6 days a week. Farmers who deal

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with livestock are used to work all week and if the gasifier supports such a work load, gasification is viable with a loan.

In no condition a gasifier would generate profit if wood chips were bought in the market, as its average price varies from US$ 70-80, almost double the average cost estimated for farmers. This difference between cost of feedstock and market price is due to farmers not having transport costs and not paying consumer taxes over the feedstock, both costs embedded in the market price.

In the initial condition of 0.55 capacity factor, yearly consumption of wood is of 104 odt, and a farmer would need to have at least 4 hectares under management for a 5-year rotation, as EMA is a high 26 odt. A total of US$4,500 of labor and land rent embedded in annual costs of production would not generate financial disbursements and could be seen as income by the farmer, as follows: US$ 193 of labor and US$ 400 of land rent in forest management, US$ 939 of labor in drying and handling chips and another US$ 3,000 as labor related to running the generator.

The local case scenario above was near static, developed in an area with good soils and high productivity, fixed conditions for electricity value, but it allowed the understanding how different variables are linked to the business.

If conditions of analysis are broadened to a generic area in South, Southeast and Central Brazil, a new range of values must be considered for all variables (Table 2).

TABLE 2: Range Of Variables Used With The Monte Carlo Technique For A Broad Range Analysis

	Min	Expected	Max
Forest production (US$/odt)	5	16	31
Preparation of feedstock (US$/odt)	22	33	44
Total cost of feedstock (US$/odt)	27	49	71
Construction of a shed for chip drying and storage (US$)	0	5,000	6,000
Specific Capital Cost (US$)	2,600	3,000	3,500
Electricity capacity factor	0.55	0.6	0.7
Value of energy (US$/kWh)	0.16	0.18	0.2
Value of excess heat generated (US$/kWh)	0	0.1	0.2
Discount rate (%)	4%	5%	6%
Loan (two separate scenarios)	No		Yes

Instead of using single values and varying one variable at a time, a Monte Carlo simulation was used. It takes multiple random values of independent variables within specific variation distribution and ranges. In this process, it may randomly

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select a low cost of wood, a low capital cost of the machine, a high capacity factor of the generator and present a resulting positive net present value, so the business would be profitable, conversely, it could take a not so favorable sample and a negative net present value would be achieved.

For instance, in the capacity factor distribution, 0.55 was considered as the minimum acceptable value and only 1.3% of the samples assumed this value, while 6.6% of samples assumed 0.6, the value set as the most frequent for capacity factor. It repeats the process for thousands of times and presents a frequency histogram with all possible results. In the current case, there was a convergence in frequency distributions with 10,000 and 50,000 interactions and graphs (Fig. 2) represent histograms of 10,000 interactions.

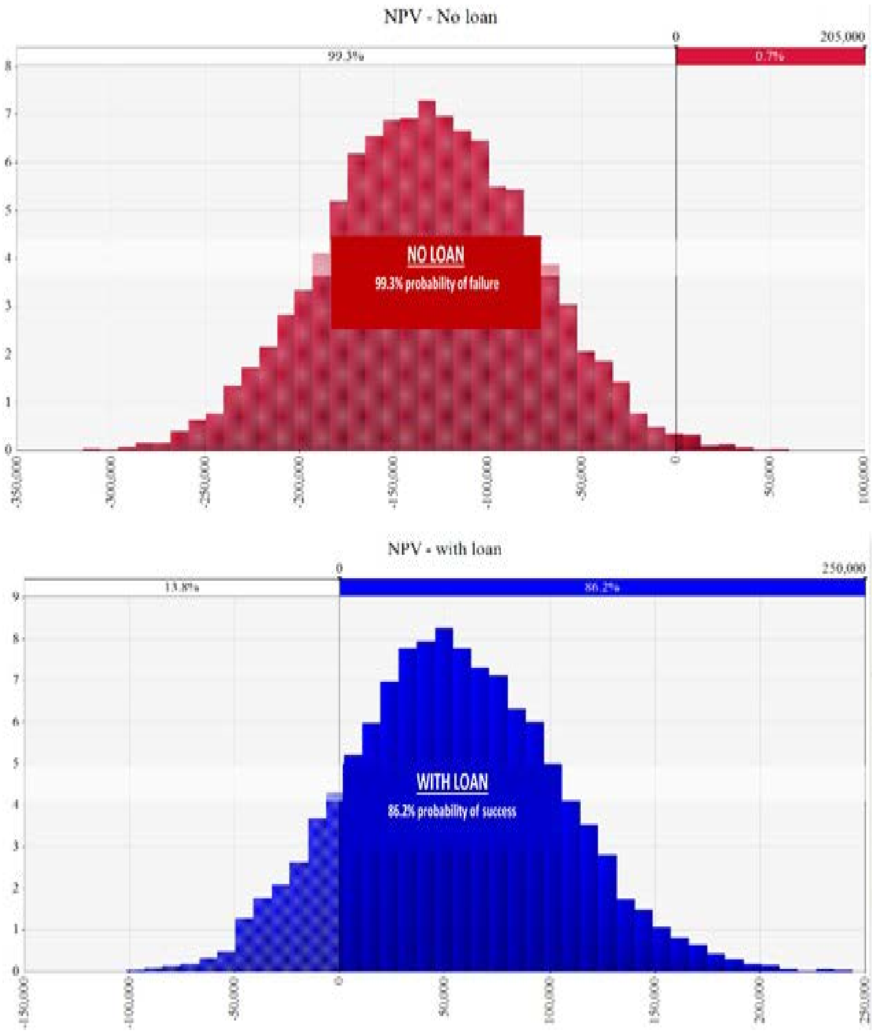

Figure 2: Probability of Profit of Gasification Systems

The same two scenarios considered with Ajuricaba farms, business with own capital and with a loan from PRONAF, were then contrasted. As it can be seen at the

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"NPV – no loan" frequency histogram of Fig. 2, only 0.7% of all cases would pay back without a loan, with an expected negative average NPV of -US$ 143,129 ± 879.74 (90% interval of confidence), meaning that the economic risk of running a gasifier is absolute. The result of the simulation with a loan is opposite, with 86.2% of probability of profit, with an expected NPV of US$ 54,311.99 ± 811.89 (90% interval of confidence).

Therefore, the loan can enable the production of renewable energy systems. Again, part of the costs of the business are not financial and that may enhance attractively.

Farmers could plant forests in their "set-aside" land and sell wood to the market. Stumpage prices of wood vary from US$ 15-30/odt, depending on the region of Brazil and in areas with pulp companies or with high demand for grain drying, where wood usually have higher prices, gasification may not be interesting at all. On the other hand, in areas of low demand for wood, electricity generation is an alternative, as prices are set by the electricity market and not by offer and demand. Currently, it is mandatory that utility companies accept micro and mini-generation if technical conditions of connection are met.

3.4. 3.4. Levelized Cost of Energy and Solar Energy

The PRONAF loan is directed to any renewable energy and could have been used in a photovoltaic system. A PV system of 35-40kW have a capital cost of US$ 2,300 (lowest of 3 quotations for a system installed at Ajuricaba).

According to the Brazilian Atlas of Solar Energy. The annual mean of daily horizontal global solar irradiation in any region of the Brazil varies from 1500 to 2500 kWh/m2. If installed in an average Brazilian insulation area, of 2,000 kWh/(m²year), it would have a levelized cost of energy (LCOE) of US$ 0.160 for a 20 year-period, slightly lower than the US$ 0.162 LCOE of a US$ 2,600/kW gasifier run with a US$ 49/odt fuel at 0.55 capacity factor and slightly higher than the US$ 0.151 of the gasifier run at 0.6 capacity factor.

Utility price is US$0.20/kWh, so both technologies could compete with it if price remain stable. There is already an emerging market for photovoltaic systems in Brazil, but the capital cost of equipment is still very high if compared with the US$1500-2000/kW found in equivalent systems in Europe (OLIVEIRA et al, 2014).

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One advantage of the PV system is that there is almost no labor involved in running it, except from periodic cleaning and eventual maintenance.

The new regulatory framework of distributed micro- and mini-generation may attract more Brazilians to produce their own electricity, but at current capital costs of renewable energy generation systems, neither gasification nor photovoltaic generation would be viable within a 12-year period without further incentives. They would be viable at a 20-year horizon, but a large initial investment would be required to little economic gain.

4. CONCLUSION

The development of integrated forestry of short rotation forests and in-farm gasification of wood chips for energy generation is technically and economically viable if some enabling conditions are present and some barriers are overcome. The loan granted by PRONAF is one of these enabling conditions. With a low interest rate and a long payback period, it requires no initial investment and increase profitability of the business. If not limited to small farmers, it would certainly bust the adoption of micro and mini-generation in rural areas and contribute to the Brazilian INDC.

Among the barriers to the development of small-scale woodchips gasification systems are the inexistence of current examples of success, the need of development of appropriate equipment for feedstock preparation and of a value chain for small-scale renewables, including the production of equipment in Brazil. A strategy of demonstration of prospects of micro-generation by research and extension would contribute to overcome some of those barriers.

REFERENCES

BOCCI, E. et al. (2014) State of art of small scale biomass gasification power systems: a review of the different typologies. **Energy Procedia**, n. 45, p.247–256. Available at: http://dx.doi.org/10.1016/j.egypro.2014.01.027. Access; 10/02/2015

BLANCHARD, R. (2015) Biomass heating. Domestic Microgeneration: Renewable and Distributed Energy Technologies, **Policies and Economics**, p.77.

BRIDGWATER, A.V. et al. (2012) **A techno-economic comparison of power production by biomass fast pyrolysis with gasification and combustion**. Available at: www.elsevier.com/locate/rser.Access: 15/05/2015

CRIEKEMANS, D. (2012) The geopolitics of renewable energy: different or similar to the geopolitics of conventional energy?. In: **ISA Annual Convention**, p. 16-19.

http://www.ijmp.jor.br v. 9, n. 1, January - March 2018
ISSN: 2236-269X
DOI: 10.14807/ijmp.v9i1.678

FRAUNHOFER, I. S. E. (2013) **Levelized cost of electricity-renewable energy technologies**. Fraunhofer Institute for Solar Energy Systems ISE, Freiburg, Germany, Tech. Rep.

KOTLER, P. (1986) The prosumer movement: A new challenge for marketers. **NA-Advances in Consumer Research**, v. 13.

LEE, U. (2013) et al., **An experimental evaluation of an integrated biomass gasification and power generation system for distributed power applications**. Applied Energy, 101, p. 699–708. Available at: http://dx.doi.org/10.1016/j.apenergy.2012.07.036.Access: 21/03/2015

DESENVOLVIMENTO AGRÁRIO (2016) **Plano de Safra 2015-2016**. http://www.mda.gov.br/sitemda/sites/sitemda/files/user_arquivos_3/ps01.pdf. Access: 22/03/2016

MINISTÉRIO DO DESENVOLVIMENTO AGRÁRIO (2016). **Programa Nacional de Fortalecimento da Agricultura Familiar**. http://www.mda.gov.br/sitemda/secretaria/saf-creditorural/arquivos-t%C3%A9cnicos-do-plano-safra. Access: 12/06/2016

OLIVEIRA, E.B.(2011) **Softwares para manejo e análise econômica de plantações florestais**. Documentos, 216, Embrapa Florestas, Colombo.

PARAGAND, Y.; SOVACOOL, B. K. (2016) Electricity market design for the prosumer era. **Nature Energ**y, v. 1, p. 16032.

REES, M. (2015) **Business Risk and Simulation Modelling in Practice**: Using Excel, VBA and@ RISK. John Wiley & Sons.

TOFFLER, A.; ALVIN, T. (1981) **The third wave**. New York: Bantam books.