Available online at www.sciencedirect.com
ScienceDirect
Renewable and Sustainable Energy Reviews
12 (2008) 883–890
RENEWABLE & SUSTAINABLE ENERGY REVIEWS
www.elsevier.com/locate/rser

Analysis of the sustainability of using wastes in the Brazilian power industry

Luciano Basto Oliveira, Maria Silvia Muylaert de Araujo*, Luiz Pinguelli Rosa, Martha Barata, Emílio Lebre La Rovere

Energy Planning Program—COPPE/UFRJ (Coordination of the Post Graduation Programs in Engineering at the Federal University of Rio de Janeiro), Centro de Tecnologia, bloco C, sala 211, Cidade Universitária, Ilha do Fundão, Rio de Janeiro, CEP: 21949-900, Brazil

Received 13 September 2006; accepted 27 October 2006

Abstract

This paper presents a methodology for analyzing the sustainability of using wastes in the Brazilian power industry. It will describe projects, both completed and under development by coordination of the post-graduation programs in engineering (COPPE) at the Federal University of Rio de Janeiro (UFRJ), for generating energy from wastes. The results of these projects were included in a doctoral thesis [Oliveira LB. Aproveitamento energético de lixo e biodiesel no Brasil (energy use of garbage and biodiesel in Brazil). Dissertation (doctoral), COPPE/UFRJ, 2004, p. 204, http://www.ppe.ufrj.br/ppe/production/tesis/lboliveira.pdf] defended in 2004 at the Energy Planning Program of the COPPE at the UFRJ—PPE/COPPE/UFRJ. The study encompasses an analysis of sustainability using a methodology developed for the above-mentioned dissertation, taking two existing methodologies into account: sustainability analysis and data envelopment analysis.

Keywords: Waste; Renewable energy; Sustainable development; Brazilian biomass

*Corresponding author. Tel.: +55 21 2562 8763; fax: +55 21 2270 1586.
E-mail addresses: Luciano@ivig.coppe.ufrj.br (L.B. Oliveira), muylaert@ppe.ufrj.br (M.S.M. de Araujo), lpr@adc.coppe.ufrj.br (L.P. Rosa), barata@lima.coppe.ufrj.br (M. Barata), emilio@ppe.ufrj.br (E.L. La Rovere).

1364-0321/$ - see front matter © 2006 Elsevier Ltd. All rights reserved.
doi:10.1016/j.rser.2006.10.013

Contents

1. Introduction

The use of wastes in the Brazilian power industry has increased in the last years although the use still is on a very small scale. Acquiring the sustainability of the residues management in the country as a whole can be an important step. The work described here is the result of the outputs obtained from some pilot projects under development by coordination of the post-graduation programs in engineering (COPPE) at Federal University of Rio de Janeiro (UFRJ), for generating energy from wastes, subject of the DSc. dissertation of Luciano Basto Oliveira, finished in 2004. The sustainable development indicators developed in 1999 for a research carried out by COPPE/UFRJ was used [2], and that research was funded by UNDP and ANEEL, on the potential of the power industry for the clean development mechanism. These indicators assess the advantages and disadvantages of carbon emissions reduction with respect to five items: technical items (analysis of the origin of materials, on-site structuring of parts, technological dependence), operational items (difficulty of assembling the parts and maintenance conditions), environmental items (noise impacts, visual impacts, odor impacts, vectors that have impact on health, impacts on animal routes, accident risk and leisure disturbance), economic-financial items (cost-benefit analysis, economies of scale, savings of hard currency reserves), and social items (demand for jobs, income generation, capturing new investments, citizenship rights).

One important methane emission source is the waste [3]. Around 5–20% from CH_4 anthropogenic annual global emission to the atmosphere are due to the anaerobic decomposition and treatment of solid and liquid residues [4]. The production of methane from liquid residues treatment in anaerobic conditions is estimated between 30 and 40 Tg per year, what represents around 8–11% of global anthropogenic emissions of CH_4 [4]. From this total, it is estimated that the industrial sector is responsible for 26–40 Tg per year, while the residential and commercial sectors are responsible for around 2 Tg per year.

Another group of indicators was also used. It was developed for a research done at COPPE/UFRJ on criteria and indicators for appraising clean development mechanism projects [5]. It was published in the article "proposal for eligibility criteria and indicators to assess projects for the clean development mechanism (CDM)" [6], presented at the IX Brazilian Energy Congress, and contributed to the development of a set of indicators called "Sustainability Analysis" [7] for application in the analysis of energy projects. The original proposal had four eligibility criteria, eight sustainability indicators and three operational feasibility indicators. This proposal was reformulated and today it has 10 indicators distributed among five areas: environmental, social, economic, technological and operational.

The methodology (comparison with the business-as-usual scenario), the grading scale and most indicators, although in a different order, are the same as in the original proposal. The following indicators were kept: contribution to the mitigation of global pollution (indicator 1), contribution to local pollution (indicator 2), net job generation (indicator 3), cost effectiveness (indicator 5), contribution to technological self-sufficiency (indicator 7), potential for technological innovation (indicator 8) and capacity for coordination and integration with other sectors (indicator 10). The new indicators added to the above group are described below:

1.1. Contribution to improving the HDI (indicator 4)

This indicator assesses the direct and indirect effects of the undertaking on the quality of life of the population affected by the undertaking, that is, in its area of influence. We propose that this assessment should take into account the influence of the undertaking on the HDI of the low-income population.

It requires the following information:

- relative weight of the population benefiting directly and indirectly with respect to the total population of the country,
- socioeconomic characteristics of the population benefiting from the undertaking,
- distributive impacts of the project for the population benefiting directly and indirectly from the undertaking, in comparison to the business-as-usual scenario,
- impacts of the undertaking on the life expectancy of the population benefiting directly and indirectly from the undertaking,
- impacts of the undertaking on the access to knowledge by the population benefiting from the undertaking.

This indicator should be assessed with respect to the invested capital.

1.2. Contribution to reducing contingency costs and to obtaining potential contingency benefits (indicator 6)

This indicator requires information on:

- contingency expenditures associated with the undertaking (e.g. compensation for accidents, cost of greenhouse gas abatement, public health costs),
- contingency benefits associated with the undertaking (e.g. contribution to a greater rate of abatement or less expenditures in compensation payments and/or compensation to third parties by the company).

This indicator should be assessed with respect to the invested capital.

1.3. Possibility of establishment and operation of the undertaking (indicator 9)

Potential for difficulties (social, environmental, political, economic and technical) in the establishment and operation of the undertaking. To assess this potential, the following information is required:

- degree of acceptance of the undertaking by the community in its area of influence,
- difficulties in equipment operation and maintenance,
- legislation at the different levels of government.

Overcoming of these obstacles should be weighed and should be expressed as a function of the time required for establishing the undertaking, according to the scale below.

Note: divide this scale into feasibility period and research level.

Very short term:	+3
Short term:	+2
Medium term:	+1
Long term:	zero
No pilot plant:	−1
No command of all the stages:	−2
Starting the technology investment:	−3

In order to minimize, as far as possible, the subjectivity of the analyst's opinion when applying sustainability analysis, with qualitative and quantitative characteristics proposed in the methodology, "data envelopment analysis", developed by Paulo Estelita from the Production Engineering Program (PEP) of the COPPE at the UFRJ was also applied in the present work. This analysis is a quantitative methodology totally based on numerical data. On applying both methodologies to a set of data, the convergence among the results will represent the sustainability.

Two case studies [1] are summarized below. One is on the use of alternative energy sources and the other on the various input materials used for biodiesel production, in comparison to diesel oil, with a view to identifying which materials should be prioritized.

2. Sustainability of alternative energy sources

Using Oliveira's work [1], in which thermo power plants using alternative energy sources are compared to natural gas powered thermo plants, whose input data are found in Table 1, the two methodologies were applied and a summary obtained, shown in Table 2.

In Table 2 the results were made compatible, taking into account the convergence criteria. This proved that, from a sustainability perspective, wastes should be prioritized as the most suitable source.

3. Sustainability of biodiesel

Current prices of input materials are such that if the analysis were to be strictly financial only wastes are competitive with diesel oil. Table 3 shows the data with indicators, other than financial ones, for the various input materials (divided into five groups) prepared by Oliveira [1] in order to analyze their sustainability.

The price used for new vegetable oils made allowances for the increase in production required to meet the energy scale, which would lead to a reduction of current prices, bringing them closer to the costs. To calculate this price, data on available planting area

Table 1
Comparison of different energy sources for thermo power generation in Brazil

	Greenhouse gas emission (t CO_2/GWh)	Job creation potential	Distributed generation potential (GWh/year)	O and M + CC Costs (US$/MWh)	Investment costs (US and dollar;/MWh)
1. Natural gas CC thermopower plant	449	600	83,220	28.00	18
2. Natural gas merchant thermopower plant	600	600	81,468	24.00	27
3. Wind	—	250	17,520	7.00	43
4. Solar	—	300	49,056	4.00	76
5. SHP	1	270	21,024	8.51	21.49
6. Rice husks	−1950	300	6833	−3.28	24.98
7. Garbage gas	−7033	1,001,400	13,000	42.78	42.56
8. Dranco	−5223	1,004,200	85,000	34.04	50.66
9. Incineration	−3113	1,004,000	120,000	32.83	49.78
10. BEM	−2163	1,006,400	92,000	38.70	29.39
11. Bagasse + straw and tips (BIG/STIG)	−53.57	250	133,296	62.53	14.96

Source: Own development.

Table 2
Comparison of two sustainability analysis methodologies for different energy generation sources

	Sustainability analysis	Data envelopment analysis	Compatibilization of both methodologies
Garbage gas + conservation	1	5	A
Accelerated digestion + garbage gas + conservation	2	6	A
BEM + garbage gas + conservation	3	2	A
Incineration + garbage gas + conservation	3	3	A
Thermopower generation with rice husks	5	1	A
Photovoltaic systems	8	11	C
Small hydropower plants–eletrosol	6	9	B
Wind energy plant–COELCE, CBEE/UFPE	7	4	B
Bagasse with straw and tips	8	7	B
Natural gas CC thermo plant	10	8	C
Natural gas merchant thermo plant	11	10	C

Source: Oliveira LB [1].

Table 3
Data on the inputs for biodiesel[a]

		Investment costs (R$/L)	O and M costs (R$/L)	(kg CO_2 Eq/L)	Number of jobs	Yield (millions of liters a year)
Wastes	Used oil + methanol	0.076	0.410	−1.294	1000	10
	Scum + methanol	0.106	0.120	−1.294	100	50
	Fat + methanol	0.076	0.570	−1.294	500	250
	Grease + methanol	0.091	0.250	−1.294	700	150
	Used oil + ethanol	0.076	0.420	−1.380	1130	10
	Scum + ethanol	0.106	0.130	−1.380	752	50
	Fat + ethanol	0.076	0.580	−1.380	3761	250
	Grease + ethanol	0.091	0.260	−1.380	2657	150
Manual	Castor beans + methanol	0.076	0.750	0.636	3,000,000	5584
	Castor beans + ethanol	0.076	0.760	0.550	3,072,838	5584
Annual mechanized	Soybeans + methanol	0.076	1.061	0.636	1,250,000	12,500
	Sunflower + methanol	0.076	1.052	0.636	1,250,000	59,375
	Soybeans + ethanol	0.076	1.071	0.550	1,413,043	12,500
	Sunflower + ethanol	0.076	1.062	0.550	2,024,457	59,375
Sustainable harvesting	Brazil nut + methanol	0.091	2.090	0.586	50,000	250
	Babassu palm + methanol	0.076	1.325	0.586	1,000,000	1700
	Buriti palm + methanol	0.751	1.290	0.586	240,000	1200
	Brazil nut + ethanol	0.091	2.100	0.500	53,261	250
	Babassu palm + ethanol	0.076	1.335	0.500	1,022,174	1700
	Buriti palm + ethanol	0.751	1.300	0.500	255,652	1200
Perennial	Dende palm + methanol	0.090	0.65	0.636	1,500,000	50,000
	Coconut + methanol	0.075	0.65	0.636	200,000	4750
	Dende palm + ethanol	0.090	0.66	0.550	2,152,173	50,000
	Coconut + ethanol	0.075	0.66	0.550	261,956	4750

Source: Own development based on EMBRAPA data and price research in domestic markets.

[a]The production potential for coconut was calculated using 20% of the available area (10,000 hectares, with an annual productivity of 2375 L/ha). In the case of dende oil, only 13.5% of the deforested area of the Amazon, the so-called "Deforestation Belt", was used. It covers an area of 50 million hectares, with an annual productivity of 7200 L/ha. Planting dende palm in part of the 90 million hectares of land available for agriculture would enable the production of up to 560 billion liters a year, making Brazil a major fuel exporter and generating up to 10 million jobs, 25% in the production of ethyl alcohol. For soybeans and sunflower, 25 million hectares were also considered, and the annual productivity of soybeans is 500 L/ha and for sunflower 2375 L/ha. In the case of castor beans, 6000 hectares were taken into account, with a productivity of 1125 L/ha. For the Babassu palm, an area of 17 million hectares was considered with an annual productivity of 100 L/ha, and for the Buriti palm, 160 thousand hectares and 7200 L/ha, respectively. The emissions from the production of vegetable oils are 0.5 kg CO_2/L, for planted material, and 0.45 kg CO_2/L for material from sustainable harvesting.

was used. Castor beans are a case in point, as they are quoted in the table at 30% of current prices. On the other hand, soybeans undergo no change in prices because of the level of competitiveness that this crop has already achieved. Wastes, whose costs should be reduced as a result of the increase of the supply of new and cheaper inputs, were analyzed conservatively, keeping today's prices.

Investments for industrial plants to use ethanol are higher than those for using methanol because of the equipment required to recycle the azeotrope that is inevitably formed by the combination of ethyl alcohol and water. But the unavailability of this figure favored the use of ethanol. The two methodologies were then made compatible, using convergence criteria, and the summary can be seen in Table 4.

4. Final considerations

Results of applying sustainability analysis and data envelopment analysis methodologies to input materials used in biodiesel production converged for most alternatives.

It is clear that wastes are the most sustainable inputs in the short term, since they obtained the best results for immediately available inputs in both methodologies.

Thus, it is evident that in natural competition, wastes should be prioritized, and scum and used oil are the most efficient when the results of both methodologies are made

Table 4
Summary of the classifications in the sustainability methodologies

	Sustainability analysis	Data envelopment analysis	Compatibilization
Used oil + methanol	5	5	A
Scum + methanol	2	4	A
Fat + methanol	8	9	B
Grease + methanol	5	7	B
Used oil + ethanol	3	1	A
Scum + ethanol	1	3	A
Fat + ethanol	5	8	B
Grease + ethanol	3	6	A
Castor beans + methanol	15	14	C
Castor beans + ethanol	13	12	C
Soybeans + methanol	21	17	C
Sunflower + methanol	21	16	C
Soybeans + ethanol	15	15	C
Sunflower + ethanol	15	13	C
Brazil nut + methanol	21	19	D
Babassu palm + methanol	15	11	C
Buriti palm + methanol	21	21	D
Brazil nut + ethanol	15	18	C
Babassu palm + ethanol	13	10	C
Buriti palm + ethanol	14	20	C
Dende palm + methanol	11	23	C
Coconut + methanol	11	25	C
Dende palm + ethanol	9	22	C
Coconut + ethanol	9	24	C
Diesel oil	25	2	C

Source: Oliveira LB [1].

compatible. The perspective of consumption higher than the amount available with these waste inputs requires plantations, specially castor beans and dende palm, as the simulation results show.

Nevertheless, Federal Government policies determined that half the replacement of mineral diesel oil by biodiesel must use castor beans, because of the social benefits that this activity will provide the Northeast region of Brazil. Since the established guidelines state that 2% of diesel oil is to be replaced since 2005, with annual increases until 5% is reached in the year 2010, as the rule for establishing the complement (of this half) has not yet been established, prioritization of wastes would not lead to controversies, as this work proved.

Since there are local and global benefits, such as environmental (greenhouse gases emissions reductions, local pollution reduction), social (job generation and income distribution), economic (reducing fuel imports), technological (paying royalties) and operational ones (capacity to install, operate and reproduce in the various Brazilian regions), the premise of this work that in light of sustainable development, the energy use of waste inputs should be prioritized, is proved.

References

[1] Oliveira LB. Aproveitamento energético de lixo e biodiesel no Brasil (energy use of garbage and biodiesel in Brazil), Dissertation (doctoral). COPPE/UFRJ, 2004. p. 204, 〈http://www.ppe.ufrj.br/ppe/production/tesis/lboliveira.pdf〉.

[2] Muylaert MS (coord). Consumo de Energia e Aquecimento do Planeta (energy consumption and global warming), Rio de Janeiro Brasil Ed COPPE/UFRJ, 2001. p. 247, 〈http://www.centroclima.org.br/imagens/consumo_energia.jpg〉.

[3] de Araujo M, Campos MS, de Christiano P, Rosa LP. GHG historical contribution by sectors, sustainable development and equity. Renew Sustain Energy Rev 2007;11(5):988–97.

[4] I.P.C.C. Revised IPCC guidelines greenhouse gas inventory: reference manual Intergovernamental panel on climate change 1996;3.

[5] Thorne S, La Rovere EL, Helio international. criteria and indicators for appraising clean development mechanism (CDM) projects, 1999 〈http://www.centroclima.org.br/CDM_Appraisal.PDF〉.

[6] Novaes ES, et al. Proposta de critérios e indicadores de elegibilidade para avaliação de projetos candidatos ao mecanismo de desenvolvimento limpo (proposal for elegibility criteria and indicators to assess projects for the clean development mechanism). In: IX congresso Brasileiro de energia, IX Brazilian energy congress, 2002:165–73.

[7] La Rovere EL, Barata M, Oliveira LB. Análise de sustentabilidade (sustainability analysis). In: Plano de desenvolvimento sustentável—(sustainable development plan) PETROBRAS. Final report, 2002.