Smart Energy

Vol.61, no.spe: e18000023, 2018
http://dx.doi.org/10.1590/1678-4324-smart-2018000023
ISSN 1678-4324 Online Edition

BRAZILIAN ARCHIVES OF
BIOLOGY AND TECHNOLOGY

AN INTERNATIONAL JOURNAL

Multi-criteria Selection of Distributed Mini Generation Systems Using Rice Husk

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ABSTRACT

This paper presents a multi-criteria methodology to support decision making for management and selection of distributed mini generation sources (GD) using rice husk. Considering the potential of residual biomass, the developed model is based on the Analytic Hierarchy Process (AHP) method to evaluate the main technological arrangements of generation against the technical, economical, social-environmental aspects. Considering the possibility of energy transformation of rice husk, the following alternatives for distributed mini generation are considered: steam turbine, gas turbine, micro turbine, fuel cells, alternative combustion engine and Stirling engine. Regarding the evaluation aspects, it is defined energy efficiency, environmental impacts, social impacts, lifespan, access to technology, generation capacity, installation cost & operation and maintenance costs. Finally, the alternatives to use rice husk with these sources are classified according scenarios turned to social-environmental and economical purposes.

Key words: biomass, rice husk, distributed mini generation, multi-criteria selection, AHP.

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INTRODUCTION

The growing emphasis on environmental conservation associated with dependence on fossil fuels has stimulated the development and use of biomass as a vital source of renewable energy [1]. At the same time, the insertion of the distributed mini generation through new bio energetic sources presents itself as a strategic alternative for the optimized performance of electric systems mainly due to added benefits, such as: diversification of the energy matrix, low environmental impact, shorter installation time, increased reliability of the electrical system, a secondary use of rice husk, possibility of operating independently, reduction of losses due to the lower load of the conductors, improvement of voltage levels, among others [2].
In the context of electricity generation, the share of biomass in the Brazilian energy matrix has evolved about four times in the last ten years, currently representing 8.8% of installed capacity [3]. In addition, in [4] it is foreseen the expansion of this generation source in more than 50% until 2024, which shows its potentiality and importance in to complement power generation.
Among bio energetic alternatives appears the rice husk, considered a solid agricultural residue from the process of this cereal. Brazil is the ninth largest rice producer in the world and the largest outside Asia, having harvested about 12.4 million tons in 2015 [5]. In addition, a national production of 7.2% has been projected for the next ten years [5]. Due to the characterization of continuous production by the processing industries and the low density of the rice husk, one of the most common destinations of this residue is the composting aiming at the reduction of organic matters [6]. However, this purpose triggers several environmental problems, mostly related to emission of polluting gases due to the slow decomposition as organic matter [6].
Only in Rio Grande do Sul, a state that holds 68% of the Brazilian rice production generatinges 1.68 million tons of waste annually, it is estimated that 80 MW of electric power will be generated with this biomass, being 75% higher than the installed capacity of Brazil [7]. The availability of rice hulls in the processing plants boosts the research and projects to implement distributed mini generation systems, with regards to the energetic use of biomass in electric power generation.
With respect to the technological routes for electric power generation with rice husk, it is possible to find several works that apply different concepts for energy transformation, mainly linked to thermochemical processes (direct combustion, gasification and pyrolysis) and biological processes (anaerobic digestion and cellulosic fermentation) [8]. The most common technological procedures for that are the use of: steam turbine, gas turbine, micro turbine, fuel cells, alternative combustion engine and Stirling engine [8].
On the other hand, in the adoption of new generation sources, the application of concepts inserted in the sustainable development also aims at economic, social and ecological balance of the enterprise [9]. Many papers mentioning factors for this growing trend are minimization of environmental and social impacts in choosing such generation alternative [10], which evidences the search for mechanisms to manage these selection criteria. Nevertheless, the multidimensional nature of objectives, sometimes conflicting each other, makes planning and decision making-a complex taskto select the best choice of technological arrangement.
Multi-criteria methods are considered important tools of management and support for decision making [11]. They refer to the solution and choice of the most satisfactory and harmonious choice alternative, considering a set of the previously established criterial and models that incorporate the interests and preference of the decision agent [11]. With regard to the selection of distributed sources for mini generation of energy, it is possible to find out researches with application of compensatory methods developed

by other countries such as the American choice of AHP and non-compensatory methods developed by the French school, such as PROMETHEE, ELECTRE [11]. It is also possible to find out works with hybrid methods, such as MACBTEH and integration with fuzzy logics [12].

MATERIALS AND METHODS

Multi-criteria Review: Main Aspects of the Methodology

This paper proposes the development of a multi-criteria methodology for the technological selection of distributed mini generation systems using rice husk. The main purpose is to find the most appropriate source for electric power generation under the light of six possible alternatives that considers eight sub criteria of technical, economical, environmental and social origin. In addition, scenarios with social-environmental and economical relevance were created for the simulation.

Sources of distributed mini generation were initially defined in this paper for application of the proposed methodology and the evaluation criteria were then defined. Next, the database was defined containing information with qualitative and quantitative attributes as criteria of each generation source, and the structuring problem was established through a hierarchical chain. Finally, scenarios were created to corroborate the simulation and application of the proposed method.

Sources of Distributed Mini Generation

This paper evaluates the main sources of distributed mini generation using rice husk as: steam turbine (ST), gas turbine (GT), micro turbine (MT), fuel cells using biogas or hydrogen (FC), alternative combustion engine (MC) and Stirling engine (SE).

Evaluation criteria and database

Table 1 shows the criteria defined to evaluate technological alternatives, according to the technical, economic, social and environmental nature, their identification and characterization of the attribute. Table 2 and Table 3 present the quantitative and qualitative database, respectively, for the application of the proposed methodology.

Table 1 -Criteria identification for the evaluation of alternatives

Criteria	Subcriteria	Identification	Attribute
Technical	Electrical Efficiency	EE	Quantitative
	Generation Capacity	GC	Qualitative
	Technology Access	TA	Qualitative
Technical	Life Cycle	LC	Quantitative
Economical	Installation Cost	IC	Quantitative
	Operation and Maintenance Cost	O&M	Quantitative
Environmental	Environmental Impacts	EI	Qualitative
Social	Social Impacts	SI	Qualitative

Table 2 - Quantitative database for application of the methodology

Attributes	Quantitative			
Criteria / Alternatives	EE (%)	LC (years)	IC (US$/kW)	O&M (US$/kWh)
ST	25	20	1000	0,004
GT	30	15	2000	0,010
MT	28	20	2200	0,009
FC	50	8	6000	0,001
MC	35	20	1200	0,012
SE	30	10	2500	0,014

Table 3 - Qualitative database for application of the proposed methodology

Attribute	Qualitative ("the higher, the better")			
Criteria / Alternatives	GC (0 a 1)	TA (0 a 1)	EI (0 a 1)	SI (0 a 1)
ST	0,4	1	0,6	1
GT	0,4	1	0,6	0,9
MT	0,9	0,7	0,65	0,9
FC	0,6	0,4	0,8	0,9
MC	0,9	0,9	0,7	0,9
SE	0,7	0,7	0,6	0,9

Each sub criterion corresponds to a certain characteristic, according to its nature:

- Electrical efficiency (EE): refers to the useful amount of electric energy supplied by the primary source of biofuel, that is, the efficiency in the energy conversion process of the rice husk for electric power generation.
- Generation Capacity (GC): refers to the reliability and adaptability of the technology in the constant attendance of the electric demand.
- Technology Access (TA): evaluates qualitatively the technological characterization of the system, considering the technological maturity rate and its penetration in international markets; the existence of feasible and analogous equipment and alternatives (also called technical spin off).
- Life Cycle (LC): refers to the estimated lifespan of the plant.
- Installation Cost (IC): consists of all expenses related to the cost to install the project: purchase of mechanical equipment, technological facilities, interconnection to the electrical network (if necessary), engineering services, other construction works.
- Operation and Maintenance Cost (O&M): refers to the cost of operation (which includes employee salaries and the operation of the plant) and the maintenance cost (related to corrective actions of the system, as well as to prolong lifespan and avoid failures that may lead to operation suspension).
- Environmental Impacts (EI): evaluates the environmental impacts related to the ecological scope and environment from the point of view of the bioenergy use of biomass, climate change and reduction of polluting gases.
- Social Impacts (SI): sub criterion that evaluates the social benefits related to: job generation and decentralized energy generation.

Organizational Problem

Figure1 illustrates the structure of the problem contemplating the criteria and alternatives for application of the multi-criteria method in order to support the decision-making process.

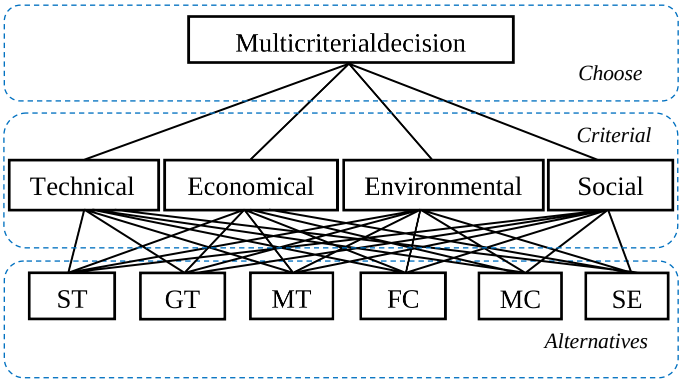

Figure 1 - Structuring the problem through hierarchy

Rating relevant criterion

Rating the relevant criteria were defined by their social-environmental and economic relevance in order to establish scenarios for simulation and to obtain results. In this way it was established:

- Social-environmental scenario - 1st Environmental Impacts, 2nd Social Impacts, 3rd Electrical Efficiency, 4th Life Cycle, 5th Generation Capacity, 6th Technology Access, 7th Installation Cost and 8th Operation and Maintenance cost.
- Economic scenario - 1st Installation Cost, 2nd Operation and Maintenance Cost, 3rd Life Cycle, 4th Technology Access, 5th Generation Capacity, 6th Electric Efficiency, 7th Social Impacts 8th Environmental Impact.

ANALYTIC HIERARCHY PROCESS

The Analytic Hierarchy Process (AHP) proposed by Saaty[13] is a compensatory method for solving ordering problems. His theory reflects the decision-making of human reasoning, in which the elements are distributed in groups, according to the attribution of their common properties. In this way, reasoning is structured in a hierarchical way for a decision to be made later. The basis of the hierarchical analysis consists in the decomposition and synthesis of the relationships between the criteria, approaching a better response due to the prioritization of their indicators. Each alternative and criterion is evaluated with the degree of importance in relation to each other, established according to a numerical scale of values for comparison, also called weight.

The choice for application of the AHP method among several other analysis options was based on the ease of access to the theoretical basis, as well as the evaluation of the simulations developed for each instance, which better assists and contributes to the understanding of the final results.

Description of the AHP steps

Briefly, the application of the AHP method is characterized by three steps. In the first step, it was constructed the parity comparison matrix (PCM) of alternatives according to equation 1. All these evaluations were performed considering a numerical scale, as shown in Table 4. In the sequence, it was calculated the relative priorities (RP) among the alternatives considering each criterion separately. The RP is obtained through normalization of the matrix established by equation 2, and the calculation of the mean value by equation 3. After that, the consistency of the judgment was verified through calculation of the consistency ratio (RC). In order to calculate this indicator, the AHP makes use of a consistency index (CI) to avoid comparisons with a high level of inconsistency, according to equation 4. Finally, the CR is obtained by the ratio between CI and the random consistency index (RCI) according to equation 5. According to [14], the index found in RC should not be higher than 10%.

$$M = \begin{matrix} & \begin{matrix} C_1 & C_2 & \cdots & C_n \end{matrix} \\ \begin{matrix} C_1 \\ C_2 \\ \vdots \\ C_n \end{matrix} & \begin{bmatrix} 1 & a_{12} & \cdots & a_{1n} \\ a_{21} & 1 & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n1} & \cdots & 1 \end{bmatrix} \end{matrix} \quad (1)$$

where *M* represents the criteria comparison matrix, *C1*, *C2*, *Cn* indicate the number of evaluation criteria, *aij* is the degree of importance of each criterion *i* on the criterion *j*.

Table 4 - Numerical scale for comparison and judgments

Numerical scale	Importance Degree
1	Same importance
3	Moderate
5	High
7	Very High
9	Extremely important
2. 4, 5, 8	Intermediate Amounts

$$a_{ij}^{*} = \frac{a_{ij}}{\sum_{k=1}^{n} a_{ik}} \quad (2)$$

$$w_k = \sum_{i=1}^{n} \frac{a_{ij}^{*}}{n} \quad (3)$$

where w_k is the weight of the criterion *k* and *n* is the number of criteria.

$$IC = \frac{\lambda_{max} - n}{n - 1} \quad (4)$$

where $\lambda_{max} - n$ represents the deviation of judgments in relation to the consistency and *n* is the matrix order.

$$RC = \frac{IC}{IR} \quad (5)$$

In the intermediate stage, it was proceeded the same mathematical way as in the initial stage, but this time was calculated the RP between all the criteria for each of the perspectives in question.

Finally, in the last step, the values of the weights of the alternatives were multiplied by the weights obtained in each criterion, considering separately each perspective. These multiplications originated a new matrix, where the cells of each row must be summed, resulting in the final PR of each alternative. The best value found will be the best technological option, that is, the preferred option of the scenario in question.

RESULTS AND DISCUSSION

Table 5 illustrates the weights among the alternatives after applying the above described methodology, while Table 6 presents the weights between the criteria in the two assessment scenarios. Finally, Table 7 and Table 8 present the calculated final relative priorities (RFW) and the final classification (CL) of the technological alternatives in the social-environmental and economic scenario, respectively.

Table 5 - Determination of weight among alternatives

Criterion 1 - Energy Efficiency (RC = 0,08238)							
	ST	**GT**	**MT**	**FC**	**MC**	**SE**	**RP**
ST	1,00	0,33	0,50	0,11	0,20	0,33	0,05
GT	3,00	1,00	3,00	0,14	0,20	1,00	0,13
MT	2,00	0,33	1,00	0,13	0,20	0,25	0,07
FC	9,00	7,00	8,00	1,00	5,00	7,00	0,76
MC	5,00	5,00	5,00	0,20	1,00	5,00	0,35
SE	3,00	1,00	4,00	0,14	0,20	1,00	0,14
Criterion 2 – Life Cycle (RC = 0,064452)							
	ST	**GT**	**MT**	**FC**	**MC**	**SE**	**RP**
ST	1,00	5,00	1,00	9,00	1,00	7,00	0,42
GT	0,20	1,00	0,20	7,00	0,20	5,00	0,15
MT	1,00	5,00	1,00	9,00	1,00	7,00	0,42
FC	0,11	0,14	0,11	1,00	0,11	0,33	0,04
MC	1,00	5,00	1,00	9,00	1,00	7,00	0,42
SE	0,14	0,20	0,14	3,00	0,14	1,00	0,06
Criterion 3 – Installation Cost (RC = 0,077609)							
	ST	**GT**	**MT**	**FC**	**MC**	**SE**	**RP**
ST	1,00	3,00	5,00	9,00	3,00	5,00	0,61
GT	0,33	1,00	3,00	5,00	0,50	3,00	0,24
MT	0,20	0,33	1,00	6,00	0,25	2,00	0,14
FC	0,11	0,20	0,17	1,00	0,13	0,14	0,04
MC	0,33	2,00	4,00	8,00	1,00	4,00	0,35
SE	0,20	0,33	0,50	7,00	0,25	1,00	0,12

Criterion 4 - Operation and Maintenance cost (RC = 0,06519)							
	ST	**GT**	**MT**	**FC**	**MC**	**SE**	**RP**
ST	1,00	5,00	5,00	0,33	7,00	7,00	0,40
GT	0,20	1,00	0,50	0,13	2,00	4,00	0,11
MT	0,20	2,00	1,00	0,14	3,00	4,00	0,15
FC	3,00	8,00	7,00	1,00	9,00	9,00	0,72
MC	0,14	0,50	0,33	0,11	1,00	3,00	0,07
SE	0,14	0,25	0,25	0,11	0,33	1,00	0,04
Criterion 5 - Generation Capacity (RC = 0,058709)							
	ST	**GT**	**MT**	**FC**	**MC**	**SE**	**RP**
ST	1,00	1,00	0,14	0,20	0,14	0,17	0,05
GT	1,00	1,00	0,14	0,20	0,14	0,17	0,05
	ST	**GT**	**MT**	**FC**	**MC**	**SE**	**RP**
MT	7,00	7,00	1,00	5,00	1,00	3,00	0,49
FC	5,00	5,00	0,20	1,00	0,20	0,33	0,16
MC	7,00	7,00	1,00	5,00	1,00	3,00	0,49
SE	6,00	6,00	0,33	3,00	0,33	1,00	0,25
Criterion 6 - Technology Access (CR = 0,050882)							
	ST	**GT**	**MT**	**FC**	**MC**	**SE**	**RP**
ST	1,00	1,00	5,00	9,00	3,00	5,00	0,49
GT	1,00	1,00	5,00	9,00	3,00	5,00	0,49
MT	0,20	0,20	1,00	5,00	0,25	1,00	0,11
FC	0,11	0,11	0,20	1,00	0,14	0,20	0,04
MC	0,33	0,33	4,00	7,00	1,00	4,00	0,26
SE	0,20	0,20	1,00	5,00	0,25	1,00	0,11
Criterion 7 - Environmental Impacts (RC = 0,008391)							
	ST	**GT**	**MT**	**FC**	**MC**	**SE**	**RP**
ST	1,00	1,00	0,50	0,20	0,33	1,00	0,11
GT	1,00	1,00	0,50	0,20	0,33	1,00	0,11
MT	2,00	2,00	1,00	0,33	0,50	2,00	0,21
FC	5,00	5,00	3,00	1,00	3,00	5,00	0,64
MC	3,00	3,00	2,00	0,33	1,00	3,00	0,32
SE	1,00	1,00	0,50	0,20	0,33	1,00	0,11
Criterion 8 – Social Impacts (RC = 0)							
	ST	**GT**	**MT**	**FC**	**MC**	**SE**	**RP**
ST	1,00	3,00	3,00	3,00	3,00	3,00	0,56
GT	0,33	1,00	1,00	1,00	1,00	1,00	0,19
MT	0,33	1,00	1,00	1,00	1,00	1,00	0,19
FC	0,33	1,00	1,00	1,00	1,00	1,00	0,19
MC	0,33	1,00	1,00	1,00	1,00	1,00	0,19
SE	0,33	1,00	1,00	1,00	1,00	1,00	0,19

Table 6 - Determination of weight among criteria

Scenario 1 – social-environmental									
	EE	**LC**	**IC**	**O&M**	**GC**	**TA**	**EI**	**SI**	**RP**
EE	1,0	3,0	7,0	8,0	6,0	5,0	0,3	0,5	0,2
LC	0,3	1,0	6,0	7,0	4,0	4,0	0,2	0,3	0,1
IC	0,1	0,2	1,0	3,0	0,2	0,3	0,1	0,1	0,0
O&M	0,1	0,1	0,3	1,0	0,2	0,2	0,1	0,1	0,0
GC	0,2	0,3	5,0	6,0	1,0	3,0	0,1	0,1	0,1
TA	0,2	0,3	3,0	5,0	0,3	1,0	0,1	0,2	0,0
EI	3,0	5,0	9,0	9,0	7,0	7,0	1,0	2,0	0,3
SI	2,0	4,0	8,0	9,0	7,0	6,0	0,5	1,0	0,2

Table 7 - Final classification of alternatives - socio-environmental scenario

Sources	Final RP	Classification
ST	0,149	3º
GT	0,114	6º
MT	0,245	4º
FC	0,426	1º
MC	0,282	2º
SE	0,119	5º

Table 8 -Final classification of alternatives - economic scenario

Sources	PR Final	Classification
ST	0,440	1º
GT	0,197	5º
MT	0,210	4º
FC	0,259	3º
MC	0,291	2º
SE	0,101	6º

CONCLUSIONS

With the results obtained for this paper is concluded that rice husk is a viable alternative for decentralized energy generation and techniques of multi-criteria decision support point to a harmonious solution in face of the exposed criteria and possible technological alternatives. The most relevant options of the described problem considering the socio-environmental scenario and the economic scenario were: fuel cell and steam turbine, respectively. The results obtained with the AHP method were satisfactory since they were met the considerations observed in [14].

This paper considers analyzes of projects aimed at distributed mini generation using rice husk. However, projects with other types of residual biomass using the same methodology could be also evaluated. It is worth mentioning that the scenarios were previously designed to incorporate the influence of stakeholders in decision making. In addition, it is important to highlight the need for constant revision of the technical data regarding the technological alternatives. Such measures contribute to the reliability of management and selection of the alternatives.

As a follow-up of this work, mathematical modeling is being carried out to estimate the real potential of distributed generation, according to the available residual biomass available, also considering the technological alternatives for evaluation of the joint generation of electric and thermal power - cogeneration of energy.

ACKNOWLEDGMENTS

The authors express their gratitude to UFSM for providing research facilities and the laboratory assistance of CEESP for their help.

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Received: December 21, 2017;
Accepted: August 01, 2018