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SELECTION OF *BRIQUETTING* PRESS FOR BIOMASS ENERGY DENSIFICATION: APPLICATION OF THE AHP-GAUSSIAN, CRITIC-WASPAS, AND CRITIC-WISP METHODS

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ABSTRACT

This work aims to select a biomass briquetting machine for energy studies applied in the processes of continuous roasting and gasification in the pilot plant of the Polytechnic School of the Federal University of Bahia. The selection of the equipment will be carried out using the AHP-Gaussian, CRITIC-WASPAS, and CRITIC-WISP methods. Six (6) models of briquetting presses were analyzed, and selected according to their operational characteristics. The criteria used in the selection of the equipment were cost (R$), energy consumption (kW), and production (kg/h). The methods of support for decision-making applied were chosen for ranking because they do not depend on the peer-to-peer analysis of the criteria by the decision-makers. Model 03 was the best positioned in the ranking, followed by model 02 and model 01. The comparative analysis of the results provided shows that models 03 and 02 showed similarity in the ordering and that, in the case of

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Revista ARACÊ
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applying the normalized Gaussian factor as weight, the WASPAS method shows sensitivity regarding the parameter λ.

Keywords: Energy Densification. Biomass. Briquetting machine. AHP_Gaussiano. CRITIC-WASPAS-WISP.

Revista ARACÊ
ISSN: 2358-2472

INTRODUCTION

The application of biomass *in natural* or processed for energy purposes, despite not being something new, has been gaining more and more attention from the scientific community about the improvement of technologies already used (Raj, Tirkey, and Jena, 2023) and the development of new processes (Yang et al., 2023) that increase the energy potential of this renewable input.

Because it mainly has relatively high humidity, compared to other energy inputs, and varied particle size distribution, biomass needs, in most cases, to undergo pre-treatment processes for better efficiency in its use (Carneiro-Junior et al., 2021).

The processes of pelleting, briquetting, and roasting can be highlighted, among others, when it is intended to energetically densify the biomass for *use in situ* or for transport and subsequent application (Prakash Kumar et al., 2019). In this case, the energy densification of biomass is attractive because it makes the mode of transport more efficient since a greater amount of energy per unit volume will be displaced.

The transport of biomass is an important step in the energy chain of this input, since its application, in general, does not occur at the place of its production. The economic viability of energy-intensive production processes, that intend to use biomass as an input, strongly depends on this stage. Thus, transporting an energy-dense biomass can be decisive for its application as an energy input.

The briquette is a product manufactured through the drying and mechanical compaction of various types of biomass waste, resulting in blocks that can be cylindrical or polygonal (Silveira and Lopes, 2011). Briquettes made from biomass waste can generate up to three times more energy than firewood, having a reduced volume compared to the original waste, in addition to being recyclable, having the same calorific value, a durability that can be up to three times greater than that of firewood, and having a homogeneous shape and standardized dimensions, which simplifies its transport and manipulation (Silveira and Lopes, 2011).

The bright production process is energy-intensive as it involves drying, crushing/grinding, and pressing the biomass. Thus, the sizing and/or choice of the appropriate briuetadeira for densification must be done based on well-defined criteria such as, for example, production capacity, energy consumption, and cost of equipment for energy expenditure to be optimized.

Revista ARACÊ
ISSN: 2358-2472

An alternative for energy densification of biomass is roasting. Unlike briquette production, roasting removes both moisture and volatile compounds. This removal occurs in a temperature range of 200°C to 350°C in an inert (N2 in general) or partially oxidizing reaction atmosphere (Carneiro-Junior et al., 2021). Like the use of briuetadera, roasting also consumes energy to promote the energy densification of biomass, needing to be carefully dimensioned to make its energy application in other production chains feasible.

Pyrolysis and biomass gasification are examples of processes that benefit from the use of dense biomass, mainly through roasting. The physicochemical properties of biomass when enhanced by roasting allow both pyrolysis and gasification to have better performance indicators in their products (Wang, Kejie *et al*, 2022).

In the specific case of the gasification process, the quality of the syngas produced is improved when compared to the use of biomass *in nature* and the same biomass This fact confirms that the application of dense biomass, in particular torrefied, is on the rise, even with the energy expenditure inherent to the process (Im-Orba and Arpornwichanop, 2021).

The importance of studies to improve or develop technologies for biomass energy densification is perceived by the growing number of publications of studies on the subject in the literature, which reinforces the benefits of the application of this input.

The present work aims to select/indicate, among options available in the market, a biomass briquetting machine for energy studies of roasting and gasification in a pilot unit existing at the Polytechnic School of the Federal University of Bahia. For this, methods to support decision-making will be applied.

Decision-making support methods are applied in several areas of knowledge and are present in large numbers in the literature. Depending on the number of criteria and alternatives, the most appropriate method for modeling the problem can be selected or methods can be combined for this purpose (Menekşe and Camgöz Akdağ, 2023).

The method called MCDM (multi-criteria decision-making) can order alternatives by confronting criteria that have a clear and manifest trade-off, whether quantitative, qualitative, or both (Patel, Mehta, and Sharma, 2023).

The methods chosen, depending on the characteristics of the problem, were CRITIC-WASPAS, CRITIC-WISP, and AHP-Gaussian because they do not necessarily require the evaluation of the criteria by decision-makers.

Revista ARACÊ
ISSN: 2358-2472

THEORETICAL FOUNDATION

In this subsection, the theoretical foundations necessary for the methodological development of the present work are presented.

AHP-GAUSSIAN METHOD

The AHP-Guassiano method was developed from the AHP method proposed by Prof. Saaty (Saaty, 1980), differing from it by the fact that it does not require the peer-to-peer evaluation of the criteria by the decision makers, eliminating the cognitive effort of this stage, as well as the demand for time necessary for this analysis when the problem presents a high number of criteria (Santos, dos and Santos, dos, 2021). Another advantage of the AHP-Gaussian method is the possibility of analyzing problems with several criteria greater than fifteen (15), a limitation that exists in the original AHP method.

CRITICAL METHOD

The main objective of the CRITIC method is to weigh the importance of the criteria in a multicriteria decision-making problem, through the correlation between them (Diakoulaki, Mavrotas, and Papayannakis, 1995). Therefore, the CRITIC method has been widely applied together with other multicriteria methods to support decision-making.

The steps of application of the CRITIC method are:

Construction and normalization of the decision matrix: The normalization of the decision matrix differentiates the cost criteria (Equation (1)) from the benefit criteria (Equation (2)). The superscript "+" indicates the highest value of each criterion, while the superscript "-" indicates the smallest value among them.

$X_{ij} = \frac{r_{ij} - r_i^+}{r_i^- - r_i^+}$	(1)
$X_{ij} = \frac{r_{ij} - r_i^-}{r_i^+ - r_i^-}$	(2)

Calculate the correlation coefficient between the criteria in the normalized matrix: As a result of this step, we have a square matrix, whose order is equal to the number of criteria. Since the linear correlation between the same criterion is equal to one (1), the principal diagonal of this matrix is easily determined. Equation (3) illustrates the procedure for calculating the linear correlation between the criteria.

Revista ARACÊ
ISSN: 2358-2472

$\rho_{jk} = \frac{\sum_{i=1}^{m}(x_{ij}-\bar{x}_j)(x_{ik}-\bar{x}_k)}{\sqrt{\sum_{i=1}^{m}(x_{ij}-\bar{x}_j)^2 \sum_{i=1}^{m}(x_{ik}-\bar{x}_k)^2}}$	(3)

Calculate the Ci index for each criterion: Equation (4) indicates how the Ci factor is calculated. The σj represents the standard deviation between the values of the same criterion.

$C_j = \sigma_j . \sum_{k=1}^{n}(1-\rho_{jk})$	(4)

Calculate the weight of the criteria: The weight of the criteria, Wj, is calculated by the mean between the indices Ci, as indicated by Equation (5).

$W_j = \frac{C_j}{\sum_{j=1}^{n} C_j}$	(5)

WASPAS METHOD

The WASPAS method to be applied goes through the following stages (Assis, de, Santos, dos and Basilio, 2023):

Decision matrix construction and normalization: The decision matrix normalization process is accomplished by applying equations (6) and (7). The method normalizes the criteria of cost (1) and benefit (2) in a differentiated way.

$r_{ij} = \frac{min_i x_{ij}}{x_{ij}}$	(6)
$r_{ij} = \frac{x_{ij}}{max_i x_{ij}}$	(7)

Assigning weights to the criteria: In this step, decision-makers must assign weights (importance) to each criterion. It should be noted that the sum of the weights is equal to one (1) or 100%.

Calculate the optimization criteria: The optimization criteria of the WASPAS method are based on the weighted sum (WSM), $Q^{(1)}$, and weighted product (WPM) methods $Q^{(2)}$. Equations (8) and (9) provide the values of the optimization criteria $Q^{(1)}$ and $Q^{(2)}$.

Revista ARACÊ
ISSN: 2358-2472

$Q_i^{(1)} = \sum_{j=1}^{n} \bar{x}_{ij} w_j$	(8)
$Q_i^{(2)} = \prod_{j=1}^{n} (\bar{x}_{ij})^{w_j}$	(9)

Determine the relative importance of each alternative, Q_i: Equation (10) illustrates the procedure for determining the relative importance of each alternative. In this equation, the parameter λ was observed, which assumes values between 0 and 1. Thus, the WASPAS method allows a sensitivity analysis relative to the weighted sum and the weighted product.

$Q_i = \lambda Q_i^{(1)} + (1 - \lambda) Q_i^{(2)}$	(3)

WISP METHOD

The WISP Method is based on other methods of aiding multicriteria decision-making, such as the WASPAS method discussed in section 2.3. Thus, the use of weighted sums, weighted products, or weighted exponentials is present in the formulation of the method (Stanujkic et al., 2023).

The steps for applying the WISP method are indicated below:

Construction of the normalized decision matrix: The normalization of the decision matrix is carried out through Equation (11).

$r_{ij} = \frac{x_{ij}}{max_i x_{ij}}$	(11)

Determination of the value of four (4) utility measures as indicated in Equations 12—15.

$u_i^{wsd} = \sum_{j \in \Omega max} r_{ij} w_j - \sum_{j \in \Omega min} r_{ij} w_j$	(12)
$u_i^{wpd} = \prod_{j \in \Omega max} r_{ij} w_j - \prod_{j \in \Omega min} r_{ij} w_j$	(13)
$u_i^{wsr} = \frac{\sum_{j \in \Omega max} r_{ij} w_j}{\sum_{j \in \Omega min} r_{ij} w_j}$	(14)

$u_i^{wpr} = \frac{\prod_{j \in \Omega max} r_{ij} w_j}{\prod_{j \in \Omega min} r_{ij} w_j}$	(15)

Where and represent the difference between the influence of the cost and benefit criteria, while and represent the influence of the ratio of these criteria, calculated based on the sum and product models weighted on the final utility of the alternative.$u_i^{wsd} u_i^{wpd} u_i^{wsr} u_i^{wpr}$

Recalculate the values of the four used according to Equations 16—19.

$\bar{u}_i^{wsd} = \frac{u_i^{wsd}}{(1 + u_{maxi}^{wsd})}$	(16)
$\bar{u}_i^{wpd} = \frac{u_i^{wpd}}{(1 + u_{maxi}^{wpd})}$	(17)
$\bar{u}_i^{wsr} = \frac{u_i^{wsr}}{(1 + u_{maxi}^{wsr})}$	(18)
$\bar{u}_i^{wpr} = \frac{u_i^{wpr}}{(1 + u_{maxi}^{wsr})}$	(19)

Calculate the overall utility of each alternative, according to Equation (20).u_i

$u_i = \frac{1}{4}(u_i^{wsd} + u_i^{wpd} + u_i^{wsr} + u_i^{wpr})$	(20)

The WISP method does not differentiate between cost or benefit criteria in the decision matrix normalization procedure. The cost-benefit effect of the criteria is accounted for in the utility measures (equations 12–15).

The ordering of the alternatives takes place in ascending order of value, that is, the alternative with the highest value of the global utility will be the most indicated (Stanujkic et al., 2023).u_i

METHODOLOGY

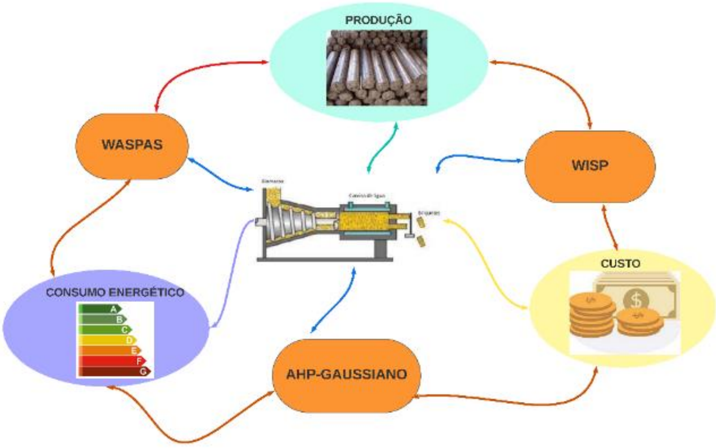
The methodology of this work involves the definition of the criteria that will be analyzed for the selection of the biomass briquetting machine through the application of the methods to support decision-making:

Revista ARACÊ
ISSN: 2358-2472

STRUCTURE OF THE PROBLEM

The problem of selecting the briquetting shop was made through discussions with the laboratory team and a survey of the demands and restrictions of the existing equipment. In this sense, the mind map illustrated in Figure 1 was made, synthesizing the methodological thinking of the central problem of this work.

Figure 1. Mental map of structuring the central problem of biomass briquetting machine selection.



Source: Author

PERFORMANCE CRITERIA AND ALTERNATIVES

Operational parameters, such as the diameter and shape of the briquette and the dimensions of the equipment, were used to select which equipment would be part of the ordering (alternatives). Thus, six (6) models of briquetting presses were chosen for analysis and ordering.

To preserve the identity of the manufacturers, only the word "model X" was adopted as nomenclature, where "X" represents only a numbering from 01 to 06. The selection criteria were defined as follows: production (t/h), energy consumption (kW) and cost (R$).

DEFINITION OF WEIGHTS (IMPORTANCE) FOR THE CRITERIA

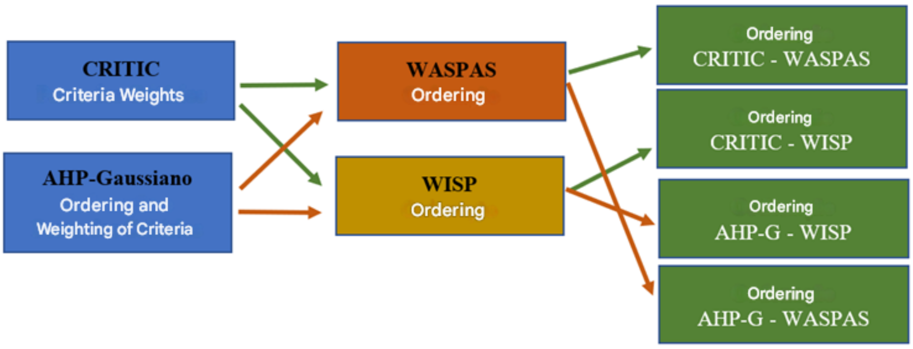
The weights (importance) for the criteria will be estimated using the CRITIC method, described in section 2.2., and will be applied in the WASPAS and WISP methods. For comparison purposes, the normalized Gaussian factor will be applied with weighting of the criteria in both the WASPAS method and the WISP method.

Revista ARACÊ
ISSN: 2358-2472

COMPARISON BETWEEN METHODS

The ordering proposed by each method will be discussed concerning the weights used to weight the criteria. In addition to the weights proposed by the CRITIC method, the normalized Gaussian factor will be used as the weight of the criteria in the WASPAS and WISP methods (Figure 2).

Figure 2. Methodological summary of the work.



Source: Author

RESULTS

The decision matrix used to model the problem is shown in Table 1. Based on the data reported in the decision matrix, the AHP-Gaussian, CRITIC-WASPAS, and CRITC-WISP methods were applied to order the alternatives (briquetting models).

Table 1. Decision matrix: briquetting models and selection criteria.

Models/Criteria	Production(t/h)	Consumption (kW)	Cost (R$)
Model 01	3,50	5,50	9600,00
Model 02	7,00	7,50	11523,25
Model 03	9,00	11,00	12487,32
Model 04	2,00	8,50	10548,35
Model 05	3,00	10,00	15658,12
Model 06	5,00	17,00	16587,22

Source: Author

The WASPAS method was applied to the same decision matrix (Table 1) to compare the ordering of the analyzed alternatives. Remember that the WASPAS method requires the decision maker to assign weights (importance) to the criteria that must be taken into account in the selection of the best equipment (alternative). Thus, to eliminate subjectivity in the choice of these weights, the CRITIC method was chosen so that these values were assigned based on the correlation between the values of each criterion, as shown in Table 2.

Revista ARACÊ
ISSN: 2358-2472

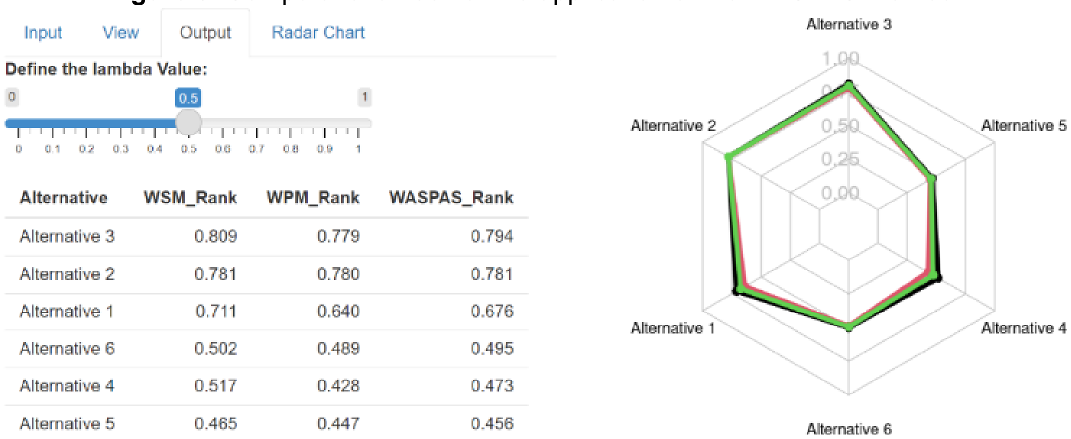
Table 2. Weights are assigned using the CRIT method.

Criteria	Weights (%)
Production(t/h)	47,24
Consumption (kW)	25,80
Cost (R$)	26,96

Source: Author

Figure (3) illustrates the computational tool developed by Barbara and Santos (2023) to facilitate the application of the WASPAS method.

Figure 3. Computational tool for the application of the WASPAS method.



Alternative	WSM_Rank	WPM_Rank	WASPAS_Rank
Alternative 3	0.809	0.779	0.794
Alternative 2	0.781	0.780	0.781
Alternative 1	0.711	0.640	0.676
Alternative 6	0.502	0.489	0.495
Alternative 4	0.517	0.428	0.473
Alternative 5	0.465	0.447	0.456

Source: adapted from BARBARA and SANTOS (2023).

The ordering performed by the WASPAS method, using the weights suggested by the CRITIC method, recommends model 3, followed by models 2 and 1. It is observed that there is a proximity between models 3 and 2, justifying a critical look by the art of the decision-makers. In Figure 3, the parameter "λ" was considered equal to 0.5, that is, considering that the contributions of the weighted sum and product are equal. Even if you change the value of this parameter to the extremes (0 and 1), the suggested ordering has not changed.

Figure 4 illustrates the ordering performed using the WISP method, with the weights suggested by the CRITIC method. For the WISP method, model 02 was indicated, followed by models 03 and 01. Thus, there was an inversion between the first and second places indicated by the CRITIC-WASPAS and CRTIC-WISP methods. The third place remained in the indication of the two methods in the same way as the model that was in the last position.

Revista ARACÊ
ISSN: 2358-2472

Figure 4. Ordering of the models using the WISP method.

MÉTODO WISP

UTILIDADES

	ui_wsd	ui_wsp	ui_wsr	ui_wpr
Modelo 1	-0,056	0,171	0,767	14,104
Modelo 2	0,066	0,346	1,220	17,233
Modelo 3	0,102	0,438	1,277	13,940
Modelo 4	-0,195	0,083	0,349	4,746
Modelo 5	-0,249	0,119	0,388	4,076
Modelo 6	-0,265	0,193	0,497	3,773
Máximo	0,102	0,438	1,277	17,233

UTILIDADES NORMALIZADAS

	ui_wsd	ui_wsp	ui_wsr	ui_wpr	ui
Modelo 1	-0,0506	0,1187	0,3368	0,7735	**0,2946**
Modelo 2	0,0601	0,2406	0,5358	0,9452	**0,4454**
Modelo 3	0,0929	0,3048	0,5608	0,7646	**0,4308**
Modelo 4	-0,1773	0,0576	0,1534	0,2603	**0,0735**
Modelo 5	-0,2257	0,0826	0,1702	0,2236	**0,0627**
Modelo 6	-0,2405	0,1341	0,2184	0,2069	**0,0797**

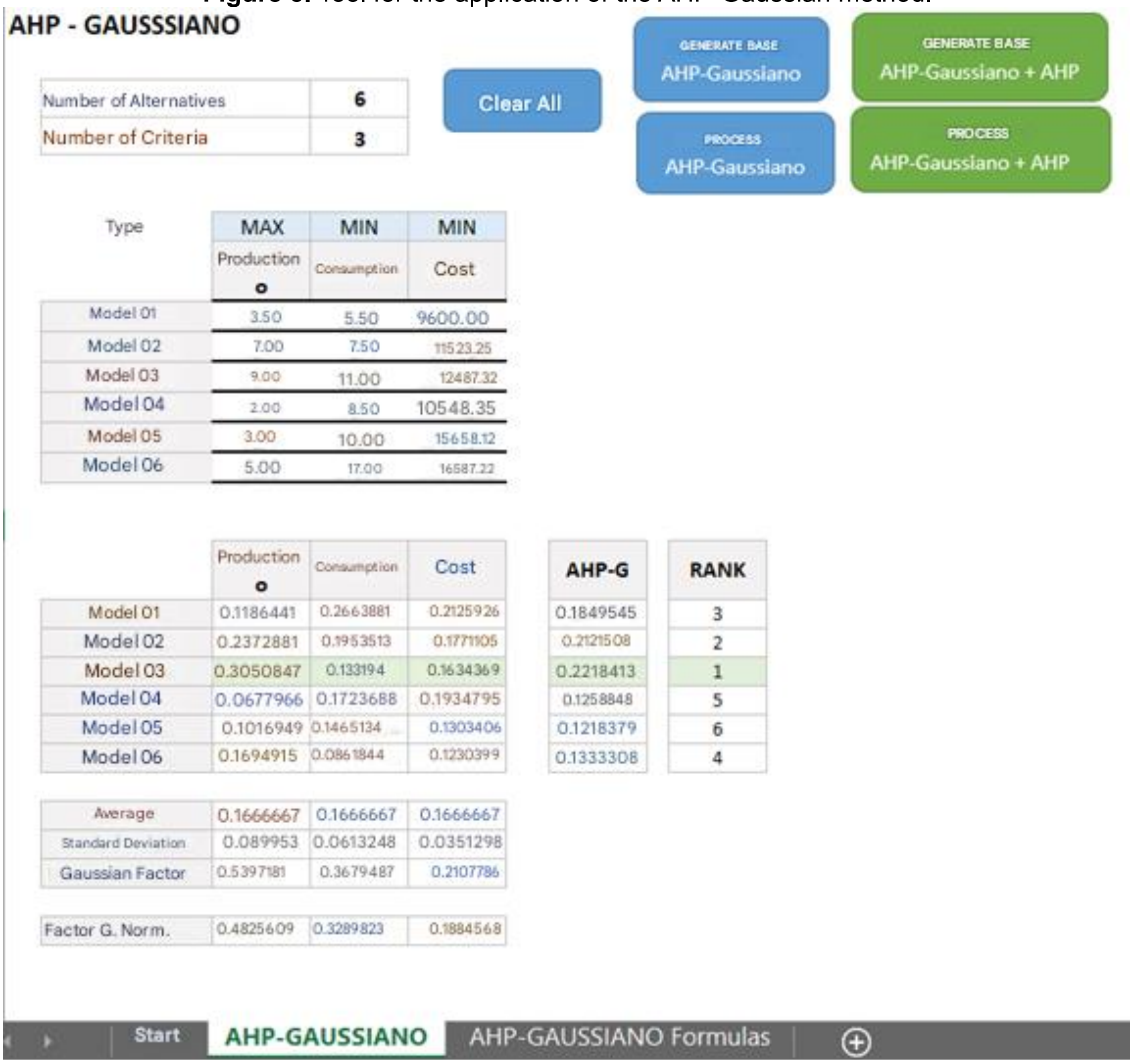
Modelo Indicado:	0,4454
Pior Modelo:	0,0627

Source: Author

The computational tool illustrated in Figure (5) allows for solving the equations of the AHP-Gaussian method with agility. Thus, the decision maker does not need to know the mathematical modeling of the method, dedicating himself primarily to the analysis of the results and consequent selection of the most appropriate model.

Revista ARACÊ
ISSN: 2358-2472

Figure 5. Tool for the application of the AHP-Gaussian method.



AHP - GAUSSSIANO

Number of Alternatives	6
Number of Criteria	3

Clear All | GENERATE BASE AHP-Gaussiano | GENERATE BASE AHP-Gaussiano + AHP | PROCESS AHP-Gaussiano | PROCESS AHP-Gaussiano + AHP

Type	MAX	MIN	MIN
	Production o	Consumption	Cost
Model 01	3.50	5.50	9600.00
Model 02	7.00	7.50	11523.25
Model 03	9.00	11.00	12487.32
Model 04	2.00	8.50	10548.35
Model 05	3.00	10.00	15658.12
Model 06	5.00	17.00	16587.22

	Production o	Consumption	Cost	AHP-G	RANK
Model 01	0.1186441	0.2663881	0.2125926	0.1849545	3
Model 02	0.2372881	0.1953513	0.1771105	0.2121508	2
Model 03	0.3050847	0.133194	0.1634369	0.2218413	1
Model 04	0.0677966	0.1723688	0.1934795	0.1258848	5
Model 05	0.1016949	0.1465134	0.1303406	0.1218379	6
Model 06	0.1694915	0.0861844	0.1230399	0.1333308	4

Average	0.1666667	0.1666667	0.1666667
Standard Deviation	0.089953	0.0613248	0.0351298
Gaussian Factor	0.5397181	0.3679487	0.2107786
Factor G. Norm.	0.4825609	0.3289823	0.1884568

Start | AHP-GAUSSIANO | AHP-GAUSSIANO Formulas

Source: MOREIRA (2021).

By the ordering carried out through the AHP-Gaussian method, model 03 is the best alternative with approximately 22.18%, followed by model 02 (21.22%) and model 01 (18.50%). As observed in the other methods applied, there is a proximity between the two best-ranked models.

Table 3 shows the orders performed by the methods applied.

Revista ARACÊ
ISSN: 2358-2472

Table 3. Ordering of alternatives by the proposed methods.

Models/Method	CRITIC-WASPS	CRITIC-WISP	AHP-GAUSSIAN
Model 01	3	3	3
Model 02	2	1	2
Model 03	1	2	1
Model 04	6	6	5
Model 05	4	4	6
Model 06	5	5	4

Source: Author

The methods partially diverge in the positioning of the last ordered models, but because they are numerically distant from the first-placed models, they do not influence the judgment of decision-makers in the choice of the best equipment options.

The normalized Gaussian factor was used as the weighting of the criteria in the WASPAS and WISP methods to verify the variability in the ordering of the alternatives.

Table 4 summarizes the results obtained in the simulation. It is observed that in essence the ordinances were maintained, which reinforces the robustness of the methods employed.

However, unlike the situation in which CRITIC was used to generate weights, the ordering by the WASPAS method presented sensitivity to the parameter "λ". For values of $\lambda < 0.28$, models 02 and 03 alternated positions. Thus, model 03 can receive the indication of the best option for the three (3) methods used.

Table 4. Comparison of the ordering performed by the WISP and WASPAS methods with weights assigned by the CRITIC and AHP-Gaussian methods.

Models/Method	CRITIC-WASPS	AHP-G-WASPS	CRITIC-WISP	AHP-G-WISP
Model 01	3	3	3	3
Model 02	2	1 (λ<0,28) / 2 (λ>0,28)	1	1
Model 03	1	1 (λ>0,28) / 2 (λ>0,28)	2	2
Model 04	6	6	6	6
Model 05	4	4	4	6
Model 06	5	5	5	5

Source: Author.

CONCLUSION

It was possible to order the models of briquetting presses identified in the market through the AH-Gaussian, CRITIC-WASPAS, and CRITIC-WISP methods. Model 03 is the most indicated when analyzing the propositions of the applied methods.

Revista ARACÊ
ISSN: 2358-2472

Model 02 of the briquetting press deserves attention in the analysis since it was indicated as the best option by the CRITIC-WISP method and by the AHP-G – WASPAS method when the parameter $\lambda < 0.28$. Even when indicated as a second option, model 02 presents numerical proximity relative to model 03.

It was possible to perceive with the analysis carried out and summarized in Table 4 that the AHP-Gaussian method can also be used to suggest the weighting between the criteria and thus be used in a hybrid way with other methods of support for decision-making.

To consolidate the application of the AHP-Gaussian method as a proponent of criteria weighting in hybrid applications, it is suggested that the scenarios proposed in this work be analyzed by other methods to support decision-making, such as MOORA, and TOPSIS, among others.

With the selected equipment, it is then possible to condition the available fresh biomass to meet the specifications of the roasting and gasification processes, about the average diameter and moisture of the briquette particles.

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Revista ARACÊ
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