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RANKING OF IMPROVED TECHNOLOGY WOOD STOVES THROUGH THE ANALYTIC HIERARCHY PROCESS (AHP) METHOD OF OPERATIONS RESEARCH

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ABSTRACT
The search for sustainable energy solutions is essential for communities that still rely on wood stoves. The right choice of improved technology stoves and renewable fuels remains a challenge, due to the environmental impact of wood consumption and associated emissions. Despite studies on the efficiency of wood stoves, there is a gap in the application of robust and automated multicriteria methodologies to simultaneously compare stove efficiency, wood consumption and heat output. This study uses the Analytic Hierarchy Process (AHP) method to order and rank Eucalyptus grandis wood stoves based on the criteria of efficiency, power and wood consumption. Automated implementation via scripts in the R software allowed for graphical analysis and detailed comparisons. The data showed that the improved stove with an elongated chimney (Efficiency, Ef = 13.05%, Wood consumption, F = 0.66 kg/h, Power, P = 0.38 kW) stood out as the most efficient and sustainable option, achieving the highest priority in the ranking with a weight of 0.44. The improved stove with a short chimney (Ef = 14.10%, F = 0.97 kg/h, P = 0.60 kW) was in second place, with a weight of 0.40, while the traditional stove (Ef = 0.86%, F = 2.64 kg/h, P = 0.10 kW) had the lowest priority, with a weight of 0.17. It is concluded that the adoption of advanced technologies, combined with the use of renewable fuel, can significantly reduce firewood consumption and mitigate environmental impact.

Keywords: Renewable Biomass. Clean technology. Multicriteria analysis. Decision Making.

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INTRODUCTION

Decision-making is a central aspect in personal, professional and corporate management, especially in sectors that demand efficient and sustainable solutions. In the field of Forest and Environmental Engineering, the choice of alternatives that best meet the needs of users, as in the case of the use of wood stoves, requires robust methodological approaches. One of the tools widely used in this context are the multicriteria decision-making methods, with emphasis on the *Analytic Hierarchy Process* (AHP), a cardinal technique that combines science and systematization, to obtain better results in complex decision-making processes.

The cardinal AHP method was developed in 1977 by Prof. Thomas Saaty (1977) of the Wharton School of the University of Pennsylvania (Saaty, 2008), based on a modeling theory that allows the use of qualitative and quantitative methods with rich applications in decision theory, conflict resolution and decision-making models (Santos et al., 2021). This method is used to analyze problems, building hierarchies and assigning weights to multiple criteria, while performing intuitive and consistent comparisons to pairs using predefined scales (Saaty, 2008). The AHP method is based on the principle that in making decisions, the experience and knowledge of researchers are at least as valuable as the data used. The AHP method is a method to assist in complex decision-making. More than determining the correct decision, the AHP helps researchers choose and justify their choice (Lira et al., 2022; Saaty, 2008; Santos et al., 2021).

Regarding the application of the AHP method in the context of energy use for cooking food, it is important to inform that the efficiency of wood stoves can vary between 5% and 30%, depending on the capacity to convert wood energy into heat, the technology used and the type of construction of the stove (Lau et al., 2013). However, this efficiency can be increased with the use of suitable insulating materials in the combustion chamber, such as glass wool and rock wool, which are widely used due to their excellent heat retention performance (Sutar et al., 2015; Urmee & Gyamfi, 2014; Yunusa et al., 2023). The main environmental advantage of increasing the efficiency of these stoves is the significant reduction in wood consumption. By reducing the amount of fuel needed to generate the same amount of heat, it contributes to the preservation of forest resources and, consequently, to the mitigation of environmental impacts associated with deforestation (Mehetre et al., 2017).

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Regarding the fuel used in the wood stove, renewable sources become essential to reduce the pressure on native forests, in this way, the Eucalyptus genera, from planted forests, are used for energy purposes in Brazil, being considered renewable sources. These species stand out for their rapid growth compared to native species, allowing for more cutting cycles in the same period and greater biomass production (Pena-Vergara et al., 2022). Additionally, the genera Eucalyptus are known for their great genetic variability, occupying about 10.2 million hectares of planted tree areas in Brazil, with an estimated average growth of 33.7 m^3/ha.year (IBÁ, 2024).

This study proposes the use of the multicriteria decision-making method *Analytic Hierarchy Process* (AHP), for ordering and ranking different types of portable wood stoves with improved technology, based on criteria such as efficiency, power and fuel consumption.

METHODOLOGY

For the development of this research, three wood stoves were used: 1) Improved wood stove with small chimney; 2) Improved wood stove with elongated chimney and; 3) Traditional wood stove, Fig. 1 to 3. Stoves 1 and 2 were built with two prismatic metal containers with rectangular faces, with a capacity of 18 liters each and an internal combustion chamber of zinc in the shape of an "L". The combustion chamber was thermally insulated with refractory silica mortar, and was molded and cured under heating for 24 hours in a wood-fired furnace built inside the ground. A chimney was attached to the stove for the channeling of the volatiles, being 25 cm high and 12 cm in diameter. Subsequently, in order to make a comparison with the traditional stove, in stove 2 the chimney was lengthened to 1.20 m in height. The traditional stove (stove 3) was manufactured with cast iron, 48 cm high and 41 cm in diameter, with a chimney attached approximately 4 meters high and 12 cm in diameter. The traditional stove had a capacity for only one pan, did not have thermal insulation of the combustion chamber and was located inside a residential kitchen (Almeida & Machado, 2017).

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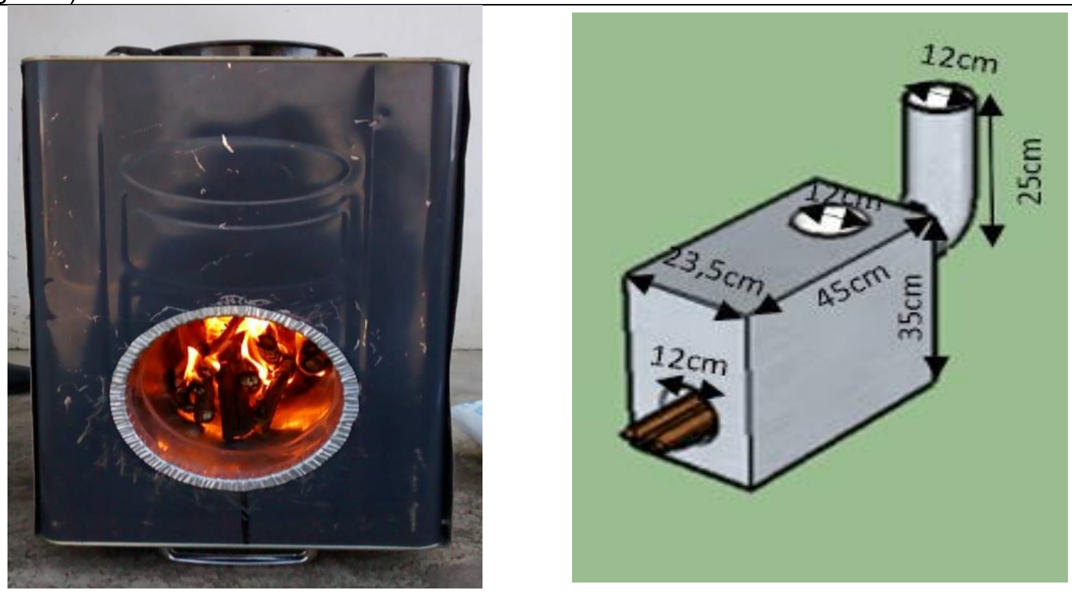
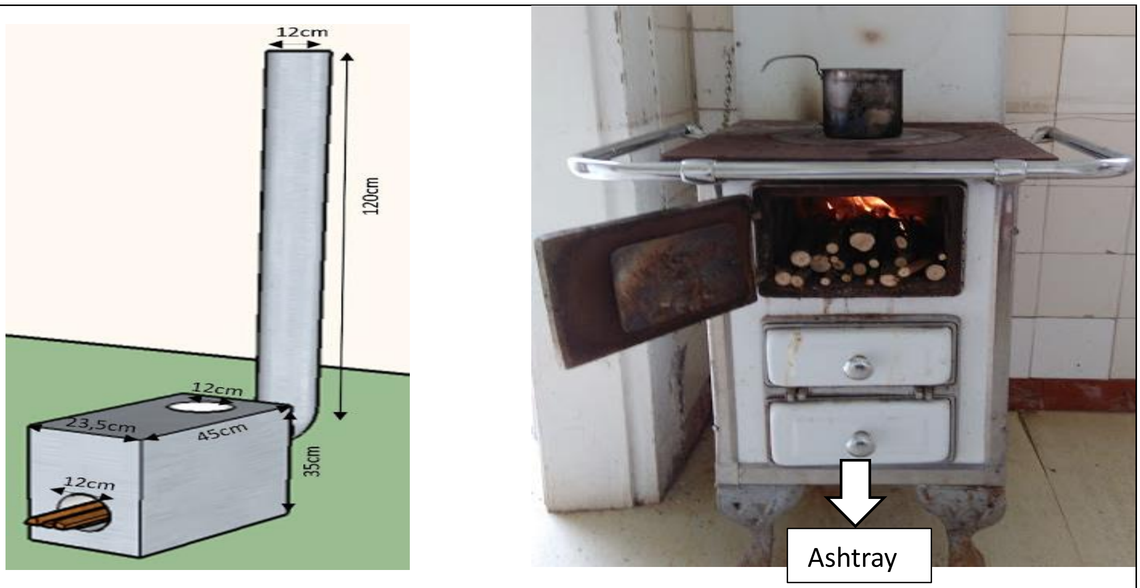
Figure 1 - Prototype of the improved wood stove with short chimney (Figure b) and photo of the improved stove (Figure a).



(a) (b)

Source: Evandro Teleginski, 2017 (Figure b).

Figure 2 – Prototype of the improved wood stove with an elongated chimney (Figure a) and a traditional stove (Figure b).



(a) (b)

Source: Evandro Teleginski, 2017 (Figure a).

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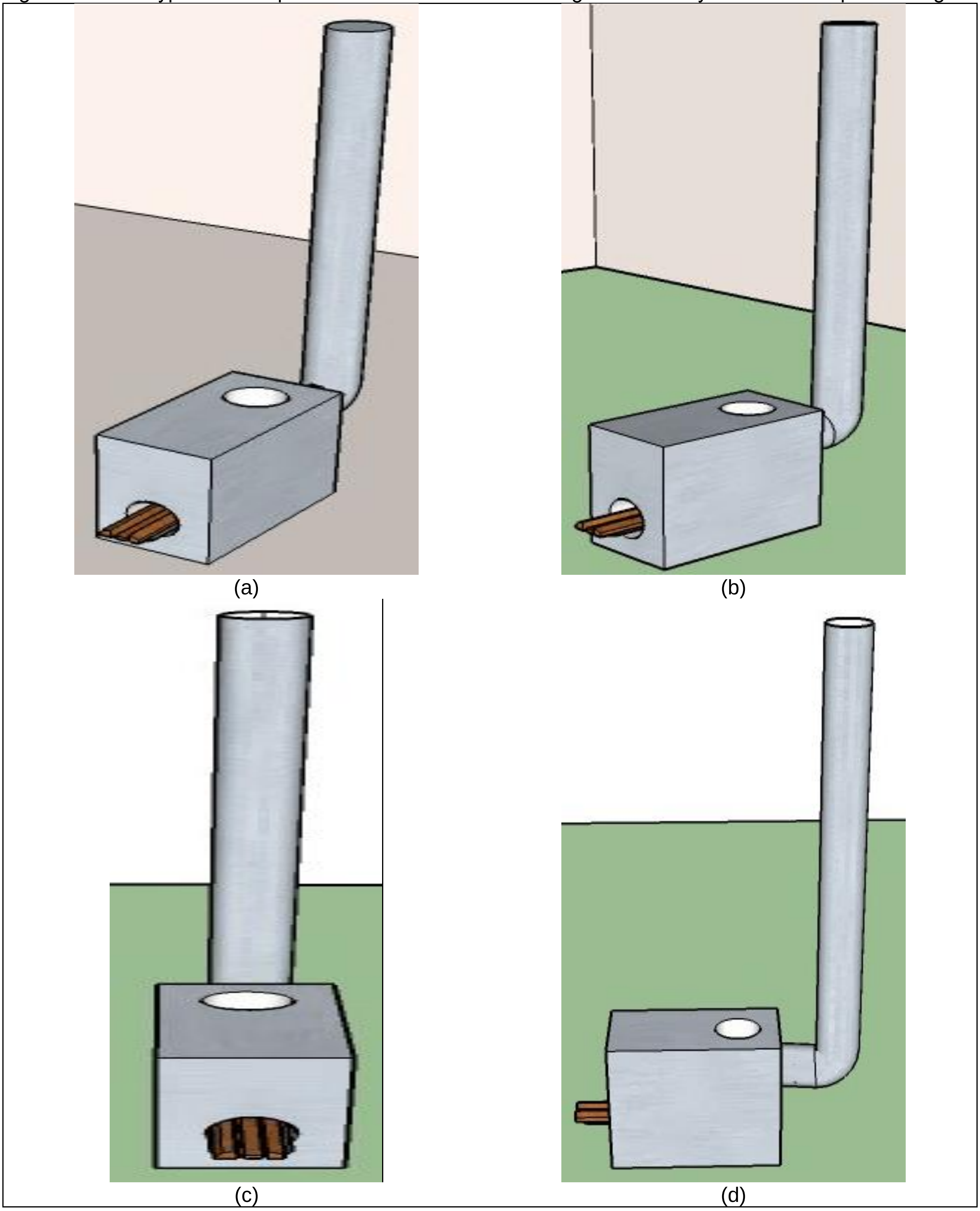
Figure 3 – Prototype of the improved wood stove with an elongated chimney at different exposure angles.



Fonte: Evandro Teleginski, 2017.

As fuel, branches of *Eucalyptus grandis* W. Hill ex Maiden with diameters in the range of 0.6 to 3.9 cm and 30 cm in length were used. The firewood used was obtained from the experimental area of the TUME (Eucalyptus Multiple Use Test) project, located at

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the Presidente Costa e Silva State Forestry Center for Professional Education, in the city of Irati, Paraná State.

The criteria used to choose the wood stove were: efficiency, wood consumption and power. Efficiency is the result of the ratio between the heat absorbed in cooking food (useful heat) and the energy released in burning wood. Efficiency is expressed as a percentage, and the higher its value, the better the stove works. The efficiency calculation was carried out according to Lau et al. (2013). The consumption of firewood was calculated by the ratio of the amount of firewood used and the time needed to heat the water and boil it for 15 minutes, being expressed in kilograms per hour. The lower the stove's consumption of firewood, the better the result. The calculation of firewood consumption was carried out according to Lupepsa & Machado, 2019. The power was defined by the amount of useful thermal energy from the burning of firewood, used in heating and boiling water for the time elapsed in the experiment. The power is expressed in Kilowatt, and the lower its value, the better the result, as it indicates a softer cooking. The power calculation was carried out according to the methodology Lau et al. (2013).

In the comparison of the improved stove and the traditional stove, the Tukey test of comparison of means was performed, preceded by the significance of the Analysis of Variance (ANOVA) at 5% probability of error.

In addition, all calculations and graphs were performed through the use of R software, which represents a methodological innovation, allowing a transparent and replicable analysis, while democratizing access to the results. The R software facilitates the application of the proposed methods in a broad and transparent manner, allowing the dissemination of the results in an accessible and collaborative way. By integrating these methods into R, the research broadens its reach, offering wood-burning stove users a practical, open-source programming language (TEAM, 2021).

For ranking and selection of wood stoves, the AHP method was applied. The AHP method is a method of analysis that seeks to reflect the natural way of decision of the human mind, being applied in the resolution of decision problems that involve multiple criteria, building hierarchies and assigning weights to the criteria, while performing intuitive and consistent comparisons in pairs using predefined scales (Saaty, 2008). The AHP method is based on the principle that people's experience and knowledge are at least as valuable as the data used to make decisions. The AHP method is a method to assist people in making complex decisions. More than determining the correct decision, the AHP helps people to order and justify their choice (Santos et al., 2021).

The AHP method divides the problem into hierarchical levels, facilitating its understanding and evaluation. At each level of the hierarchy, pair-by-pair comparisons are made of the qualitative elements of the same level, based on the importance or contribution of each of them to the element of the higher level to which they are linked. At the first level is the objective of the decision, at the second level the criteria are listed, at the third level the sub-criteria if they occur and finally, at the last level, level 4, the alternatives. In pairwise comparisons, the criteria will be connected with the objective, the sub-criteria will be compared, peer-by-pair, with their respective criteria, and the alternatives will be compared pairwise with the sub-criteria if they exist or directly to the criteria. Thus, the hierarchy of the AHP method is of the *top down type* and its main objective is to calculate the final priorities of the alternatives considering all the criteria and subcriteria of the network structure. The main idea of this method is to decompose the decision problem into a hierarchy complete enough to represent the problem under analysis, which is constituted by the objectives, criteria and alternatives, thus facilitating its understanding and evaluation (Saaty, 2008). The AHP method consists of 4 basic axioms (Table 1).

Table 1 – Axioms of the AHP method.

Residual comparisons	The elements compared pairwise by the decision-maker must satisfy the condition of reciprocity, i.e., if A is three times more preferable than B, then B will be one third more preferable than A.
Homogeneity	The elements of the hierarchy must be comparable within their level, being criterion with criterion, alternative with alternative and subcriterion with sub-criterion.
Independence	When preferences are expressed, it is assumed that the criteria are independent of the properties of the alternatives.
Completeness	It is assumed that the hierarchical structure of the decision problem has to be complete enough to represent the problem.

The pairwise comparisons made by the decision-maker result in a square decision matrix, in which the criteria are compared with each other according to the objective. Similarly, the sub-criteria are evaluated in a comparative manner in relation to the corresponding criterion, and the alternatives are compared with each other in the light of the criteria or sub-criteria, where applicable. This pair-by-pair comparison process is conducted at each level of the decision-making hierarchy, ensuring a careful evaluation at all stages of the analysis. The number of judgments necessary for the construction of a

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pairwise comparison matrix is given in Equation 1, where n is the order of the square matrix (Saaty, 2008).

$$Julgamentos = \frac{n(n-1)}{2} \qquad \text{Eq. 1}$$

The AHP method uses the Saaty fundamental scale, as shown in Table 2, to perform pair-by-pair comparisons between criteria and qualitative alternatives. The construction of the decision matrix follows two fundamental rules: the first ensures compliance with the axiom of reciprocity (Rule 1) during the comparison process, while the second establishes that every element compared to itself, whether criterion or alternative, must receive a value of 1 on the Saaty scale (Rule 2), as illustrated in Equation 2. These rules ensure that the pairwise comparison matrix is a square matrix, with the values of the principal diagonal equal to one, reciprocal and positive (Saaty, 2008).

Table 2 – Saaty fundamental scale.

1	Equal importance	Criterion compared to himself.
3	Small importance of one over the other	Experience and judgment favor one criterion over the other.
5	Great or essential importance	Experience or judgment strongly favors one criterion over another.
7	Very Important or Demonstrated	One criterion is very strongly favored over another. It can be demonstrated in practice.
9	Absolute importance	The evidence favors one criterion over another, with the highest degree of safety.
2, 4, 6 and 8	Intermediate Values	When looking for a condition of compromise between two definitions.

$$a_{ij} = \frac{1}{a_{ji}} \qquad a_{ii} = 1 \qquad \text{Eq. 2}$$

Rule 1 *Rule 2*

In the AHP method, priorities are determined through the normalization of decision matrices. This procedure aims to unify the criteria on the same scale, allowing consistent comparisons. To do this, each value in the matrix is divided by the sum of its respective column, as shown in Equation 3. This process ensures that all criteria are evaluated in a proportional and standardized manner (Saaty, 2008).

$$\frac{x_{ij}}{\sum_{i=0}^{m} x_{ij}} \qquad \text{Eq. 3}$$

After the normalization of the decision matrix, the priority vector is calculated in order to determine the order of relative importance, also called weight, of each criterion. This vector is obtained by the arithmetic average of the values present in each row of the normalized matrix, providing a consolidated measure of the relevance of each criterion in the decision-making process (Saaty, 2008).

It is essential to verify consistency in the application of the AHP method, ensuring that the judgments made in pair-to-pair comparisons are consistent. Consistency reflects the rationality of the decision-maker, assuming that if criterion A is preferred over criterion B, and B is preferred over C, then A should also be preferred over C. Mathematically, a pair-by-pair comparison matrix is considered consistent if Equation 4 is satisfied for all indices i, j and k (Saaty, 2008).

$$a_{ij} \times a_{jk} = a_{ik} \qquad \text{Eq. 4}$$

It is observed that it is rare for all comparison matrices in the AHP method to be completely consistent. Given that its construction is based on human judgments, a certain degree of inconsistency is expected and acceptable. To deal with this issue, Saaty developed a quantitative index that evaluates the consistency of the comparison matrix, called the consistency ratio (CR). This index is calculated by the ratio between the consistency index (CI) and the random index (RI) tabulated, according to Equation 5 and Table 3. If the consistency ratio is less than or equal to 10%, the matrix judgments are considered consistent. Otherwise, inconsistencies are identified, and the expert may be asked to review his or her assessments (Saaty, 2008).

$$RC = \frac{IC}{IR}$$
$$IC = \frac{\gamma_{max} - n}{n - 1} \qquad \text{Eq. 5}$$

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Table 3 - IR values for square matrices of order n

n	AND
1	0,00
2	0,00
3	0,58
4	0,90
5	1,12
6	1,24
7	1,32
8	1,41
9	1,45
10	1,49
11	1,51
12	1,48
13	1,56
14	1,57
15	1,59

N is the order of the matrix of judgments and RI is the random index.

To calculate the consistency ratio (RC) it is first necessary to obtain the largest eigenvalue () of the pairwise comparison matrix (A), obtained from Equation 6, where w is the eigenvector with the weights of the criteria. The random index is a tabulated number (Table 3) referring to the consistency index derived from a large number of pairwise comparisons made randomly, being calculated for square matrices of order n, by the Oak Ridge National Laboratory γ_{max} in the United States (Saaty, 2008). Table 3 defines the RI values as a function of the matrix order (n).

$$A \times w = \gamma_{max} \times w \qquad \text{Eq. 6}$$

If the consistency ratio was less than or equal to 10%, the overall priorities of the alternatives are calculated to verify the best decision, by ranking from best to worst. The matrix of alternatives is standardized, the values of the criteria in each alternative are added. The arithmetic means are calculated for each alternative. A vector containing these arithmetic means is assembled. This vector will present the global ranking of the alternatives according to the weight of the criteria evaluated (Saaty, 2008).

After verifying the consistency of the judgments for the criteria, with a consistency index of less than 10%, the overall priorities of the alternatives were calculated. To this end, the matrix with the numerical values of the alternatives was normalized, dividing each element of the matrix by the sum of the elements of its respective alternative. Then, the arithmetic mean of the normalized matrix was calculated, thus obtaining the relative weights of each alternative. The resulting vector of weights represents the ranking of the

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alternatives, ordering them from best to worst, according to the criteria and their respective established weights.

RESULTS AND DISCUSSION

The wood stove in this research has improved technology in relation to the traditional stove, presenting a thermal insulation system of the combustion chamber, which reduces the energy loss by conduction and by convection in the metal wall (Baldwin, 1987; Sutar et al., 2015; Urmee & Gyamfi, 2014; Yunusa et al., 2023). Additionally, heat loss occurs through the hot gases of the chimney, but the lengthening of the chimney of the improved stove did not lead to a statistically significant difference in efficiency and consumption of firewood, which suggests that the size of the chimney is not directly related to these variables, Table 4.

Table 4 – Comparison between the efficiency, wood consumption and power of the improved stove in relation to the traditional wood stove in the burning of *Eucalyptus grandis*.

Species	Ef (%)	F (kg/h)	P (kW)
FCC	14,10±1,14 a (8,10)	0,97±0,26 b (26,73)	0,60±0,15 a (25,13)
FCA	13,05±0,89 a (6,84)	0,66±0,10 b (15,17)	0,38±0,08 b (20,33)
FTR	0,86±0,12 b (13,59)	2,64±0,26 a (10,00)	0,10±0,01 c (6,85)

Being FCC enhanced wood stove with short chimney, FCA improved wood stove with elongated chimney and FTR traditional wood stove. The symbols Ef stand for efficiency, F for wood consumption and P for the heat power of the wood stove. Each mean is followed by its standard deviation. The coefficient of variation is in parentheses. The averages followed by the same letter do not differ statistically from each other. The Tukey Test was applied at the level of 5% probability of error.

Comparing the improved elongated chimney stove with the traditional stove, the results demonstrate that the improved wood stove has an energy gain, with a better use of thermal energy from burning wood (Rasoulkhani et al., 2018). This better use of energy provides savings in wood consumption and a significant increase in stove power.

The results obtained from the application of the AHP method to the criteria of efficiency, wood consumption and heat yield are presented in Table 5 and Figure 4. The pairwise comparison, based on the Saaty fundamental scale (Saaty, 2008), showed that

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the efficiency criterion had the highest relative weight, followed by the consumption of firewood, and, finally, the heat output. The consistency of the judgment was assessed using the Consistency Ratio, resulting in a value of 0.007939, which is significantly below the acceptable threshold of 0.10 as established in the AHP methodology. This result, combined with the Random Index of 0.58, confirms the internal consistency of the model used, ensuring the robustness of the weights assigned to the analyzed criteria. The hierarchy used in the application of the method can be seen in Figure 4.

Figure 4 – Hierarchy in the ranking of stoves

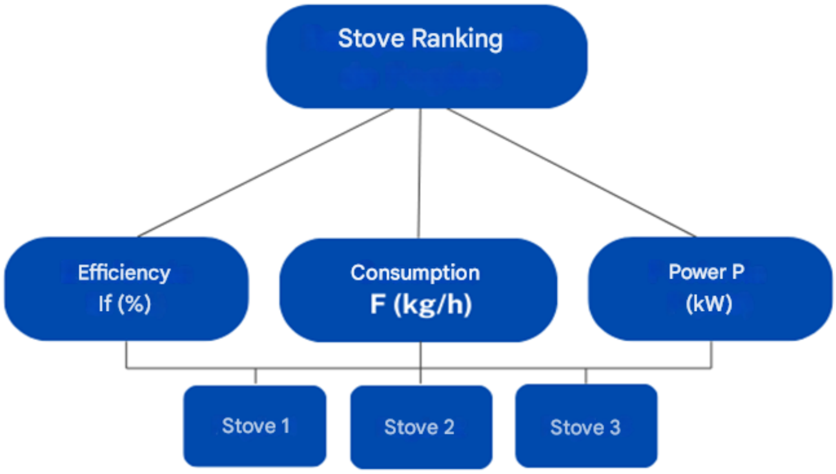

Table 5 – Weights of the criteria determined by pairwise comparison using the Saaty fundamental scale using the AHP method.

Criteria	Ef (%)	F (kg/h)	P (kW)	Pesos
Ef (%)	1	2	3	0,54
F (kg/h)	1/2	1	2	0,30
P (kW)	1/3	1/2	1	0,16

The Random Index is equal to 0.58 and the Consistency Ratio is 0.007939. We defined it in the pair-by-pair comparison, according to the Saaty scale.

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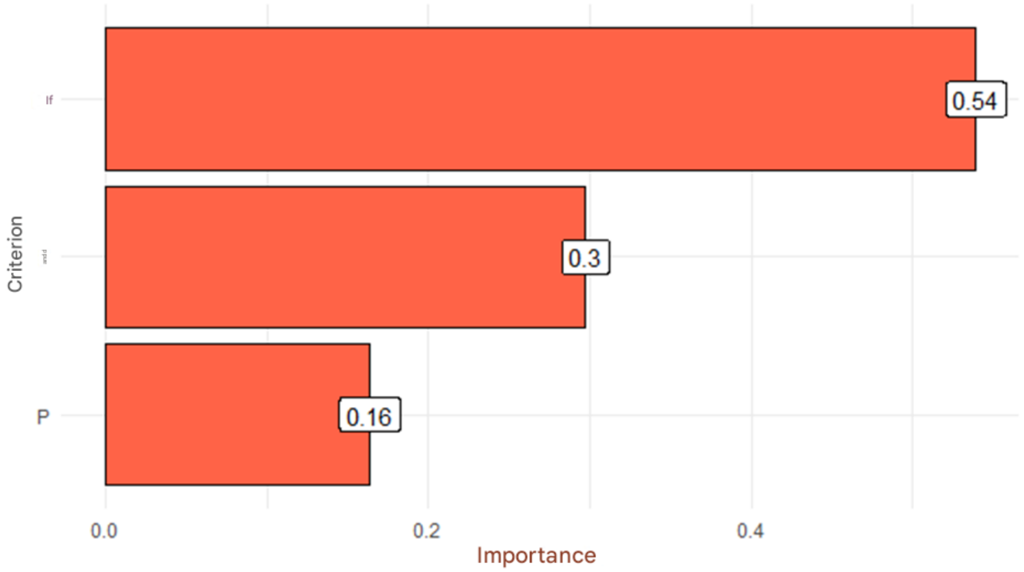
Figure 5 – Importance of the criteria according to the AHP method.



The comparison matrix resulted in weights that highlight the highest priority given to energy efficiency, Figure 5, reflecting the urgency of minimizing the use of natural resources (Ahmad et al., 2022), especially firewood from planted forests, such as eucalyptus. Firewood consumption, the second most relevant criterion, reinforces the need to reduce pressure on forest ecosystems, preserving biodiversity and ecosystem services that native forests offer (Mehetre et al., 2017). Power, as a less priority criterion, emphasizes that the focus is on maximizing energy use, promoting more efficient stoves that require less firewood, resulting in a sustainable and ecological approach to forest conservation and the reduction of the exploitation of renewable sources of biomass (Pena-Vergara et al., 2022).

The results presented in Table 6 and Figure 6 indicate the ranking of different wood stoves according to the AHP method, based on the criteria of energy efficiency, wood consumption and power. The improved stove with an elongated chimney obtained the highest priority, being classified as the most sustainable and efficient alternative. This result is due to its high energy efficiency and low firewood consumption, which directly contributes to the reduction of the demand for wood from planted forests, promoting the conservation of forest resources. The improved stove with short chimney was in second place in the ranking, also showing good energy efficiency and moderate wood consumption. In contrast, the traditional stove, which is the most used in homes, presented the lowest priority due to its low energy efficiency and high wood consumption, standing out as a less favorable alternative from an ecological point of view.

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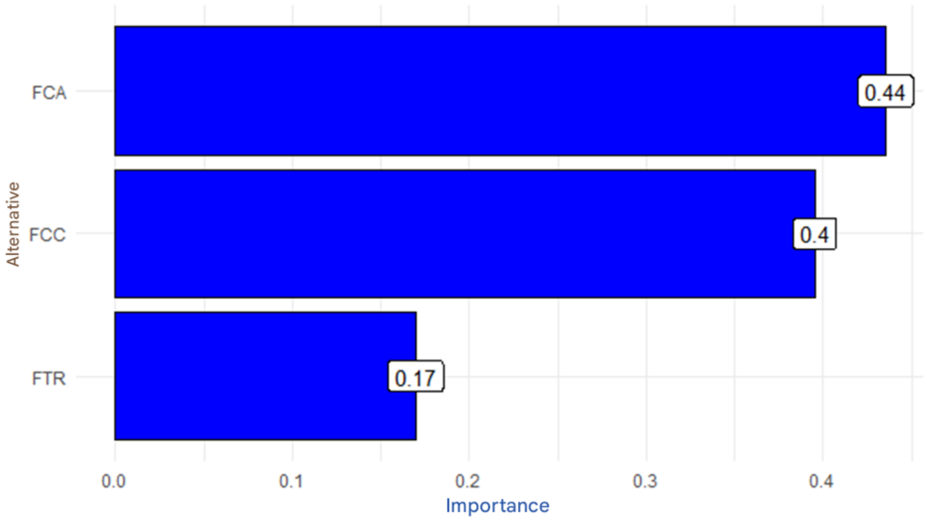
Table 6 – Ranking of wood stoves by the AHP method.

Alternatives	Ef (%)	F (kg/h)	P (kW)	Priorities	Ranking
FCC	14,10	0,97	0,60	0,40	2°
FCA	13,05	0,66	0,38	0,44	1°
FTR	0,86	2,64	0,10	0,17	3°

Being FCC Enhanced Wood Stove with Short Chimney, FCA Improved Wood Stove with Elongated Chimney and FTR Traditional Wood Stove. The symbols Ef stand for efficiency, F for wood consumption and P for the heat power of the wood stove.

Figure 6 – AHP method applied to obtain the ranking of *Eucalyptus grandis wood stoves*.



The use of efficient stoves such as FCA can thus play a crucial role in the preservation of forests, by reducing the need for firewood and, consequently, the pressure on forest ecosystems, promoting a more sustainable solution for the use of biomass.

CONCLUSIONS

The results of this study highlight that the introduction of improved technologies in wood stoves represents an efficient and sustainable solution for the use of forest biomass. The superior performance of the enhanced stove with elongated chimney (FCA), evidenced by its high energy efficiency and reduction in firewood consumption, reinforces its viability as an alternative to minimize pressure on planted forests and native ecosystems.

The application of the AHP method validated the relevance of the criteria analyzed, attributing greater priority to energy efficiency, which reflects the need to develop solutions that combine technological innovation with the conservation of natural resources. The adoption of more efficient stoves, such as the improved model evaluated, offers direct benefits for the reduction of firewood consumption, promoting the preservation of biodiversity and ecosystem services.

In addition, the results reinforce the importance of prioritizing technologies that balance the sustainable use of biomass with increased energy efficiency, contributing to responsible environmental management and mitigating the impacts of forest exploitation. This study, therefore, represents a significant contribution to forest and environmental engineering, providing technical and scientific subsidies for public policies and sustainable development initiatives focused on the efficient use of renewable energy resources.

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REFERENCES

1. Ahmad, R., Ilyas, H. N., Li, B., Sultan, M., Amjad, M., Aleem, M., Abbas, A., Imran, M. A., & Riaz, F. (2022). Current challenges and future prospect of biomass cooking and heating stoves in Asian Countries. *Frontiers in Energy Research*, *10*, 880064. https://doi.org/10.3389/fenrg.2022.880064

2. Baldwin, S. F. (1987). *Biomass stoves: Engineering design, development, and dissemination*. Volunteers in Technical Assistance [u.a.].

3. IBÁ. (2024). IBÁ - Indústria Brasileira de Árvores. http://www.iba.org/

4. Lira, K. C. S., Francisco, H. R., & Feiden, A. (2022). Classificação de fragilidade ambiental em bacia hidrográfica usando lógica Fuzzy e método AHP. *Sociedade & Natureza*, *34*(1). https://doi.org/10.14393/SN-v34-2022-62872

5. Lupepsa, B., & Machado, G. (2019). FOGÃO À LENHA PORTÁTIL METÁLICO DE TECNOLOGIA MELHORADA PARA MENOR CONSUMO DE LENHA. *Enciclopédia Biosfera*, *16*(29), 2337–2343. https://doi.org/10.18677/EnciBio_2019A178

6. Almeida, M. V. Der N, & Machado, G. O. M (2017). *Protótipo de um fogão à lenha como alternativa aos modelos tradicionais menos eficientes.* [Dissertação em Bioenergia, Universidade Estadual do Centro-Oeste].
7. http://tede.unicentro.br:8080/jspui/bitstream/jspui/1092/2/Disserta%c3%a7%c3%a3o%20Final%20-%20Milena%20Maria%20Van%20Der%20Neut%20de%20Almeida.pdf

8. Mehetre, S. A., Panwar, N. L., Sharma, D., & Kumar, H. (2017). Improved biomass cookstoves for sustainable development: A review. *Renewable and Sustainable Energy Reviews*, *73*, 672–687. https://doi.org/10.1016/j.rser.2017.01.150

9. Lau, P. C; Machado, G. O.; Nogueira, L. A. H.; Christoforo, A. L. (2013). Evaluation of the Efficiency Energy of Wood Stove from Irati Brazilian City. *International Journal of Agriculture and Forestry*, *3*(7), 267–272. https://doi.org/10.5923/j.ijaf.20130307.03

10. Pena-Vergara, G., Castro, L. R., Gasparetto, C. A., & Bizzo, W. A. (2022). Energy from planted forest and its residues characterization in Brazil. *Energy*, *239*, 122243. https://doi.org/10.1016/j.energy.2021.122243

11. Rasoulkhani, M., Ebrahimi-Nik, M., Abbaspour-Fard, M. H., & Rohani, A. (2018). Comparative evaluation of the performance of an improved biomass cook stove and the traditional stoves of Iran. *Sustainable Environment Research*, *28*(6), 438–443. https://doi.org/10.1016/j.serj.2018.08.001

12. Saaty, T. L. (2008). Decision making with the analytic hierarchy process. *International Journal of Services Sciences*, *1*(1), 83. https://doi.org/10.1504/IJSSCI.2008.017590

Revista ARACÊ
ISSN: 2358-2472

13. Santos, M. D., Costa, I. P. D. A., & Gomes, C. F. S. (2021). MULTICRITERIA DECISION-MAKING IN THE SELECTION OF WARSHIPS: A NEW APPROACH TO THE AHP METHOD. *International Journal of the Analytic Hierarchy Process*, *13*(1). https://doi.org/10.13033/ijahp.v13i1.833

14. Sutar, K. B., Kohli, S., Ravi, M. R., & Ray, A. (2015). Biomass cookstoves: A review of technical aspects. *Renewable and Sustainable Energy Reviews*, *41*, 1128–1166. https://doi.org/10.1016/j.rser.2014.09.003

15. TEAM, R. C. (2021). *R: The R Project for Statistical Computing* (Versão 4.1.1) [R]. The R Foundation for Statistical Computing. https://www.r-project.org/

16. Urmee, T., & Gyamfi, S. (2014). A review of improved Cookstove technologies and programs. *Renewable and Sustainable Energy Reviews*, *33*, 625–635. https://doi.org/10.1016/j.rser.2014.02.019

17. Yunusa, S. U., Mensah, E., Preko, K., Narra, S., Saleh, A., Sanfo, S., Isiaka, M., Dalha, I. B., & Abdulsalam, M. (2023). Biomass cookstoves: A review of technical aspects and recent advances. *Energy Nexus*, *11*, 100225. https://doi.org/10.1016/j.nexus.2023.100225