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Review

Multi-Criteria Analysis to Prioritize Energy Sources for Ambience in Poultry Production

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ABSTRACT

This paper intends to outline a model of multi-criteria analysis to pinpoint the most suitable energy source for heating aviaries in poultry broiler production from the point of view of the farmer and under environmental logic. Therefore, the identification of criteria was enabled through an exploratory study in three poultry broiler production units located in the mountain region of Rio Grande do Sul. In order to identify the energy source, the Analytic Hierarchy Process was applied. The criteria determined and validated in the research contemplated the cost of energy source, leadtime, investment in equipment, energy efficiency, quality of life and environmental impacts. The result of applying the method revealed firewood as the most appropriate energy for heating. The decision support model developed could be replicated in order to strengthen the criteria and energy alternatives presented, besides identifying new criteria and alternatives that were not considered in this study.

INTRODUCTION

The southern region of Brazil is one of the main chicken meat producers (ABPA, 2015; MAPA, 2015) due to its excellent quality and health status, as well as to its competitive price relative to pork and beef (USDA, 2015a). Brazilian broiler production has applied modern management practices, advanced health measures, balanced feeds, genetic improvement, and integrated production, which have allowed its high productivity (Nääs *et al.*, 2015; ABPA, 2015; MAPA, 2015).

However, there is still room for improvement in Brazil (USDA, 2015b), particularly in the broiler farms of the southern region of country, which productivity is significantly reduced during winter due to the low environmental temperatures (Carvalho, 2010). Bueno & Rossi (2006) mention that providing thermal comfort inside poultry houses poses a challenge, because extreme cold or heat may negatively affect production.

Environmental temperature is the physical factor that has the strongest effect on production as it affects broilers' feed intake, and consequently their weight gain and feed conversion ratio (Bueno & Rossi, 2006; AGEITEC, 2015). The provision of thermal comfort is particularly important during the early rearing phases, as broiler performance at the end of the rearing cycle is negatively affected by early suboptimal temperatures, resulting in direct losses to the farmers and ultimately reducing the productivity of the entire broiler industry (Santos *et al.*, 2009; Carvalho, 2010; Cordeiro *et al.*, 2010). Therefore, broiler facilities must ensure sufficient thermal comfort to allow birds to express their full genetic potential (Nascimento *et al.*, 2014).

Aiming at providing optimal housing temperatures to broilers reared in cold regions, artificial heating systems are applied. In southern Brazil, wood-burning furnaces or gas brooders are used for heating broiler houses (Funck & Fonseca, 2008; Carvalho, 2010; Cordeiro *et al.*, 2010). EMBRAPA (Brazilian Agricultural Research Agency) also mentions that diesel and electricity are used as heating sources, and the application of biogas and solar energy has been experimentally evaluated (Silva *et al.*, 2014).

In cold-weather regions, such as North America and Europe, the main heat sources are biomass (firewood, wood pellets, and wood chips), natural gas, and electricity (Rasga, 2013). In addition, auxiliary systems, including solar heating (Campos *et al.*, 2013) and recovery of the heat generated from the broiler house itself (Owens, 2015) have also been researched.

The thermal comfort zone of pre-starter (1-7 days old) broilers is 31-33ºC and 21-23ºC for mature broilers at a relative humidity of 65-70% (UBA, 2008). The maintenance of this comfort zone is a challenge for the farmers in southern Brazil, particularly during cold weather, as it is necessary to provide heat and reutilize the heat output of the broiler houses (Leva, 2010; Silva *et al.* 2014; Owens, 2015).

Therefore, adequate heating of broilers houses is essential to ensure broiler production quality and productivity. This, however, requires investments in equipment, acquisition of the necessary inputs for energy generation and equipment management by the farmer. The selection of the most appropriate energy source for heating poses a decision-making problem, since it is the farmer that needs to define the set of criteria and alternatives to be taken into account (UBA, 2008).

Farmers need to select an energy source to heat the broilers houses taking into consideration the investments required and the expected productivity and profitability rates. These decisions, which are often non-structured, may ultimately compromise the competitiveness of the Brazilian broiler industry.

Therefore, an exploratory study was carried out with three farmers of the mountain region of the state of Rio Grande do Sul to identify the criteria considered to select the energy source for heating broiler houses.

A systematic literature review yielded six studies, but none presented any specific association of AHP (Analytic Hierarchy Process) applied for decision-making for the selection of energy sources for heating broiler houses. The justification for this study, under the academic scope, is the limited use of the scientific approach of multicriteria analysis in decision making in broiler production. The relevance of this topic from the managerial point of view is in the generation of knowledge to support decision-making for the selection of energy sources for heating broiler houses. In addition, the criteria identified in this study may support future research on energy sources used in the broiler production chain. The main contribution of the present study is to list the energy alternatives and technical and social-environmental criteria to support decision-making using AHP. In this study, decisions were made based on social, environmental, and economic criteria that affect farmers profitability. In summary, the objective of this study was to identify the best energy source to heat broiler houses according to the farmers' professional experience and social-environmental perspectives.

MATERIALS AND METHODS

An exploratory study was conducted with three broiler farmers of the mountain region of the state of Rio Grande do Sul with the aim of identifying relevant criteria for decision-making on the energy source to be used to heat broiler houses. This exploratory study aimed at identifying the criteria taken into consideration by the farmers to select the power source used for heating broiler houses.

The following criteria were applied to select the farms to be included in the study: i) located in same geographical region in the south of Brazil, and therefore, are submitted to similar climate conditions and have similar production costs; ii) output of the same type of final product: rearing the same broiler genetic strain, grow-out period of 30 days, and broilers with 1.5 kg market weight; and iii) equal stocking density of 39 kg/m^2.

Data were collected in June 2014. The researchers visited the farms to interview the farmers, using unstructured, open-ended questions. Energy consumption, and financial and economic data were collected during the visits. Also, the researchers observed the broiler house heating process on each farm.

During the interview with the farmers, three energy sources used for heating were identified: firewood, liquefied petroleum gas (LPG), and wood pellets. However, one interviewee said he might occasionally use diesel as an energy source, and therefore, these four energy sources identified in the exploratory study were considered as alternatives.

Table 1 shows the list of interviewees, which were considered experts in broiler production in southern Brazil in the context of the present study.

Table 1 – Interviewees characteristics identified in the exploratory study.

Interviewee	Energy source used for heating	Years of experience in broiler production	Characteristics
Farmer A	Firewood	32 years	Owner
Farmer B	LPG	6 years	Owner
Farmer C	Wood pellets	4 years	Owner
Supervisor	-	12 years	Live production supervisor

The Multi-Criteria Decision Analysis (MCDA) tool was applied. The Hierarchical Analysis Process (AHP) was utilized to structure the decision-making process because it allows representing and establishing relationships based on a hierarchical structure with attribution of priorities, supporting correct decision-making (Saaty, 1991; Palcic & Lalic, 2009). This method applies a decision-making rationale with multiple criteria based on the principle that experience and knowledge are as important as the data utilized. AHP is applied in situations when intuition, rationality, and irrationality are connected with risk and uncertainty (Palcic & Lalic, 2009).

The steps of the application of the AHP method for problem-solving are:

a) contextualizing the problem;
b) structuring and defining the elements of a hierarchy;
c) building pairwise comparison matrixes, according to the Saaty's rating scale (Table 2);
d) calculating the relative priorities of the criteria relative to the objectives and of the alternatives relative to the criteria;
e) calculating consistency values;
f) calculating composite priority; and
g) interpreting the results.

Table 2 – Saaty's rating scale.

Intensity of importance	Definition
1	Equal importance
3	Somewhat more important
5	Much more important
7	Very much more important
9	Absolutely more important
2, 4, 6, 8	Intermediate values between two adjacent rates

Source: Adapted from Saaty (1990)

After the information was collected, a set of relevant criteria for deciding which was the best energy source for heating broiler houses was established. The following criteria were identified: energy source cost, lead time, and investment required to install the heating system. However, three other criteria were proposed by the researchers and accepted by the interviewees: energy efficiency, environmental impacts, and labor quality of life. It should be mentioned that the criteria proposed by the researchers were mentioned by the farmers during the interviews. Their inclusion in the evaluation comply with the demands of the foreign market, which establishes criteria relative to the disclosure of social-environmental information.

Data on energy source (raw material) cost and lead time were given by the interviewees, whereas energy efficiency data were taken from the National Energy Balance Sheet of the Brazilian Ministry of Mining and Energy (BRASIL, 2013). The environmental impact values were calculated according to the Intergovernmental Panel on Climate Change (IPCC, 2007).

Relative to the criterion 'investment in equipment', a quotation was made with the supplier that was considered the most important by the interviewees (DEBONA, 2014). Finally, in order to comparatively score the alternatives as a function of labor quality of life, information was rated according to Saaty's scale as it is a subjective criterion.

Table 3 shows the values of the criteria used to fit the ratings applied in Saaty's scale, except for quality of life, which was rated directly according to the scale from the farmers' perspective.

The second row in Table 3 corresponds the average raw material (Rm) cost used for heating the broiler house during a grow-out cycle of 30 days. The third row corresponds to the lead time (Lt) or time required for the suppliers to deliver the raw material after it was ordered. The fourth row shows the heat potential of each energy source or their energy efficiency (Ee). The environmental impact (Ei) was measured as the amount of carbon dioxide emitted by each flock. The costs of installation of heating equipment (Ie) were defined based on information obtained from companies specialized in broiler house heating.

After data collection and parametrization according to the criteria defined by the AHP method, the software Expert Choice (Choice, 2015) was applied to build pairwise matrixes, to calculate matrix priorities and consistency, and to analyze the data by building sensitivity graphs.

Table 3 – Entry data of the different energy sources.

Criterion	Base/Unit	Firewood	LPG	Diesel	Wood Pellets
Raw material cost	RM cost/flock	US$ 1,200.00	US$ 2,341.63	US$ 3,663.36	US$ 1,647.69
Lead time	Lead time in hours	48	96	168	720
Energy efficiency	Kcal/Kg	2,770	10,540	10,500	4,070
Environmental impact	Kg CO_2/flock	9,110	4,733	3,703	1,741
Investment in equipment	New equipment	US$ 19,500.00	US$ 5,000.00	US$ 20,000.00	US$ 29,500.00

RESULTS AND DISCUSSION

The first step of the multi-criteria analysis is to structure the problem, and it is considered as the most relevant step of this method (Berumen & Llamazares, 2007). Figure 1 shows the relationship between the identified energy sources and the criteria selected in this study.

It should be noted that the decision depends on the importance of each criterion as perceived by the farmers, and on the values corresponding to the industry's status in the studied region.

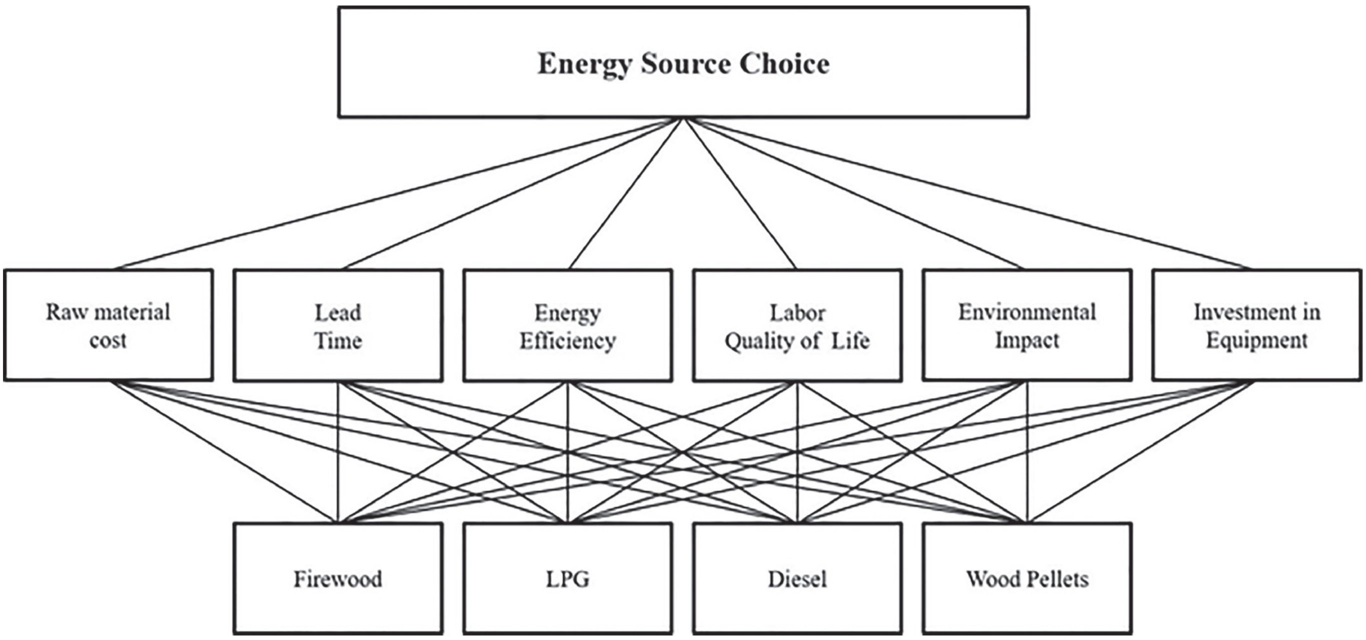

Figure 1 – Structure of the problem.

A limitation of the model is that different results may be obtained if sub-criteria are included, as different structures may yield different final results (Stillwell *et al.*, 1987). One suggestion to solve this problem is to group the criteria and sub-criteria in clusters, as recommended by Saaty (1991). However, structures showing criteria subdivided into many sub-criteria tend to have more weight than when they are considered without such detailing (Weber Eisenführ *et al.*, 1988). Therefore, the proposed model was built assuming only the minimum amount of levels: objective, criteria, and alternatives.

After the problem was structured, the pairwise comparison matrix was built (Table 4). The matrix present the distribution of the importance judgements made by the farmer during the interview.

The inconsistency value obtained for Table 4 was 0.04. According to Saaty (2008), values higher than 10% need to be reviewed as they indicate inconsistency.

Table 3 shows that the raw material cost (Rm) was considered by the farmers as the most relevant criterion when making a decision on broiler house heating equipment, as it is one of the main production costs. It also shows that there are considerable market price differences among raw materials, and, depending on the capacity of the installation, some are not viable because their high cost has a negative impact on profitability.

Table 4 – Criteria comparison matrix

Criterion	Raw material cost	Lead time	Energy efficiency	Labor quality of life	Environmental impact	Investment in equipment
Raw material cost		5.00	9.00	7.00	9.00	3.00
Lead time			5.00	3.00	5.00	(3.00)
Energy efficiency				(3.00)	1.00	(7.00)
Labor quality of life					3.00	(5.00)
Environmental impact						(7.00)
Investment in equipment	Incon: 0.04					

The criterion investment in equipment (Ie) was evaluated by the cost of purchase and installation of the heating system. This was not considered the most important item because it is related to an investment that generates expectations on the return over farm profitability, differently from the cost of raw material consumption, which is continuous and directly linked with production.

The third most relevant criterion was the lead time (Lt) of the raw material supplier. According to the farmers, the longer the lead time, the higher the uncertainties relative to raw material availability which directly impacts storage cost.

The fourth criterion in the matrix, labor quality of life (Lq), is related to the labor employed to ensure the proper function of the heating system. It includes the labor effort to generate heat in the broiler house, such as the physical effort to move the raw material from storage and feed it to the equipment, as well as health and life risks. Therefore, farmers seek equipment that is easy to operate, since it is the farmers themselves and their families that are responsible for maintaining the operation of the heating system.

Finally, relative to the energy efficiency (Ee) and environmental impact (Ea) criteria, none of the interviewees showed any interest in evaluating these parameters to base their decision-making on energy source. According to the farmers, relative to the Ee criterion, "it is the heating cost for flock production that matters." The farmers perceive energy efficiency as merely the capacity of an energy source to maintain internal broiler house temperature within the range required for production.

The farmers did not express any concern with environmental impacts, saying that the environmental impacts of poultry production – particularly of broiler production – are not relevant yet.

The comparison was made relating the energy sources to each individual decision criterion, as recommended by the AHP method. Therefore, each energy source was rated relative to each criterion, and the comparison matrices built were validated by the production supervisor.

Priorities were then normalized and calculated. Expert Choice software was used to run priorities computation and consistency tests. Figure 2 shows

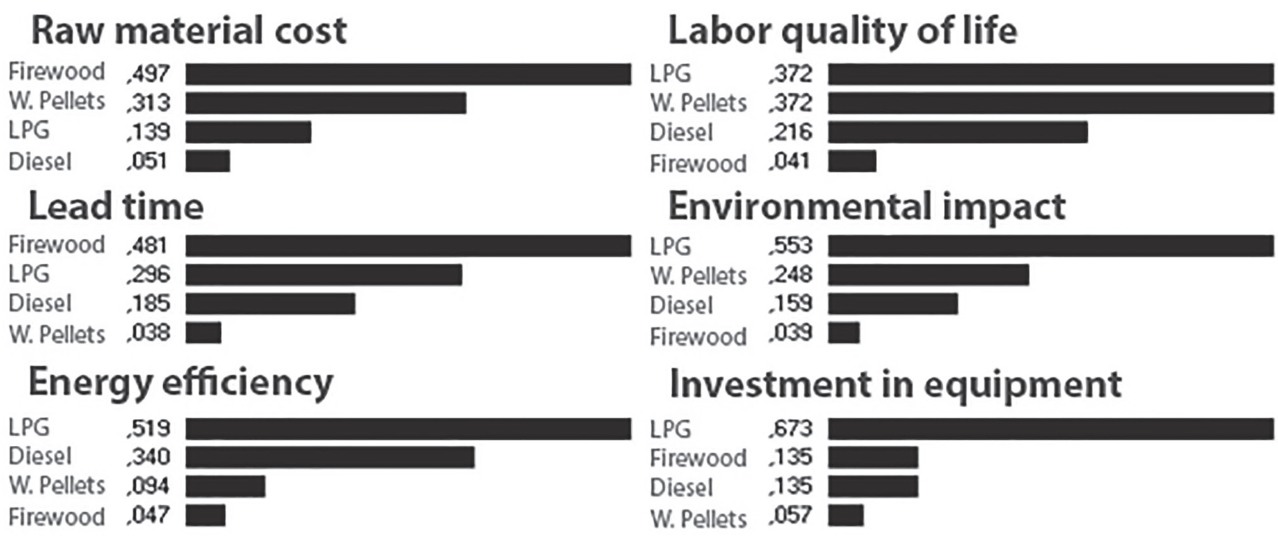

Figure 2 – Priority of the energy sources according to criterion.

the prioritization results of the matrices comparing the energy sources according to each criterion.

Firewood was the best energy source in terms of raw material cost and lead time. On the other hand, LPG was the best energy source according to the other evaluated criteria, particularly relative to social-environmental aspects. The interviews also showed that LPG was also prioritized in terms of investment in equipment (Ie) because, differently from other energy sources, LPG suppliers subsidize LPG storage tanks and tubing. When social-environmental aspects are individually analyzed, firewood presented the lowest prioritization value.

Therefore, although LPG would be preferable according to the criteria of energy efficiency, labor quality of life, environmental impact, and investment in equipment was better, firewood was chosen due to raw material cost and lead time, criteria with greater weight in the final decision.

Finally, after rating the energy sources according to each criterion, the global rating, indicating the best energy source for heating the broiler houses, is shown in Figure 3. It should be noted that the software Expert Choice allows calculating global priority using the ideal or the distributive modes. In this case, the ideal mode was the most adequate because the aim was to determine the best alternative among those not presenting any dependence relationship. Despite being independent criteria, both modes were applied and yielded the same ranking. On the other hand, when a dependence relationship among alternatives is assumed, the distributive mode should be applied (Saaty, 1991).

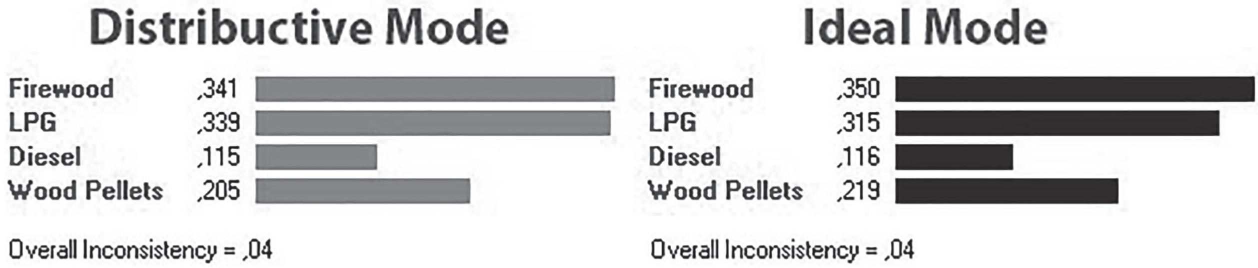

Figure 3 – Global priority

The final results show that the highest priority when making a decision on energy source was firewood, with 35% ranking value. LPG ranked second and very close to firewood results, with 31.5%. Wood pellets and diesel follow in the third and fourth positions, respectively, both summing 33.5% of the global result.

In order to better understand the small difference between the two first alternatives, a sensitivity analysis of the energy sources relative to raw material cost, which was considered the most relevant criterion by the farmers, was performed. The result is shown in Figure 4.

Figure 4 shows the four formats offered by Expert Choice software to display sensitivity analysis results. The windows "Performance Sensitivity" and "Dynamic Sensitivity" show the same information of the specific weighting of the criteria as lines or figures, respectively. The window "Head-to-Head Sensitivity" shows the comparison of the performance of two specific alternatives for each criterion, and also assumes a specific weighting of the criteria. The window "Gradient Sensitivity" presents the overall information, which were further analyzed.

The vertical line indicates the importance of the Rm criterion, which represents 47.5% of the overall weight. The figure shows that firewood ranked the highest, followed by LPG, wood pellets, and finally diesel. The rankings and their respective values at the intersection with the other lines represent the results shown in Figure 2. This chart reveals that the difference between the first two alternatives is smaller than when evaluated according to individual criterion (Figure 1), justifying the sensitivity analysis presented in Figure 4, which assumes different importance values for the Rm criterion. For importance values between 47.5% and 100%, the only change is the alternative that indicates that wood pellets become more interesting than LPG.

The dotted line vertical line indicates that, reducing the importance of the Rm criterion to a lower value, of approximately 40%, for instance, LPG would become the preferred alternative and firewood, the second option. Finally, if the importance of the Rm criterion were higher than 70%, the ranking of the results would be the same as that indicated when this criterion was individually considered (firewood, wood pellets, LPG, and diesel).

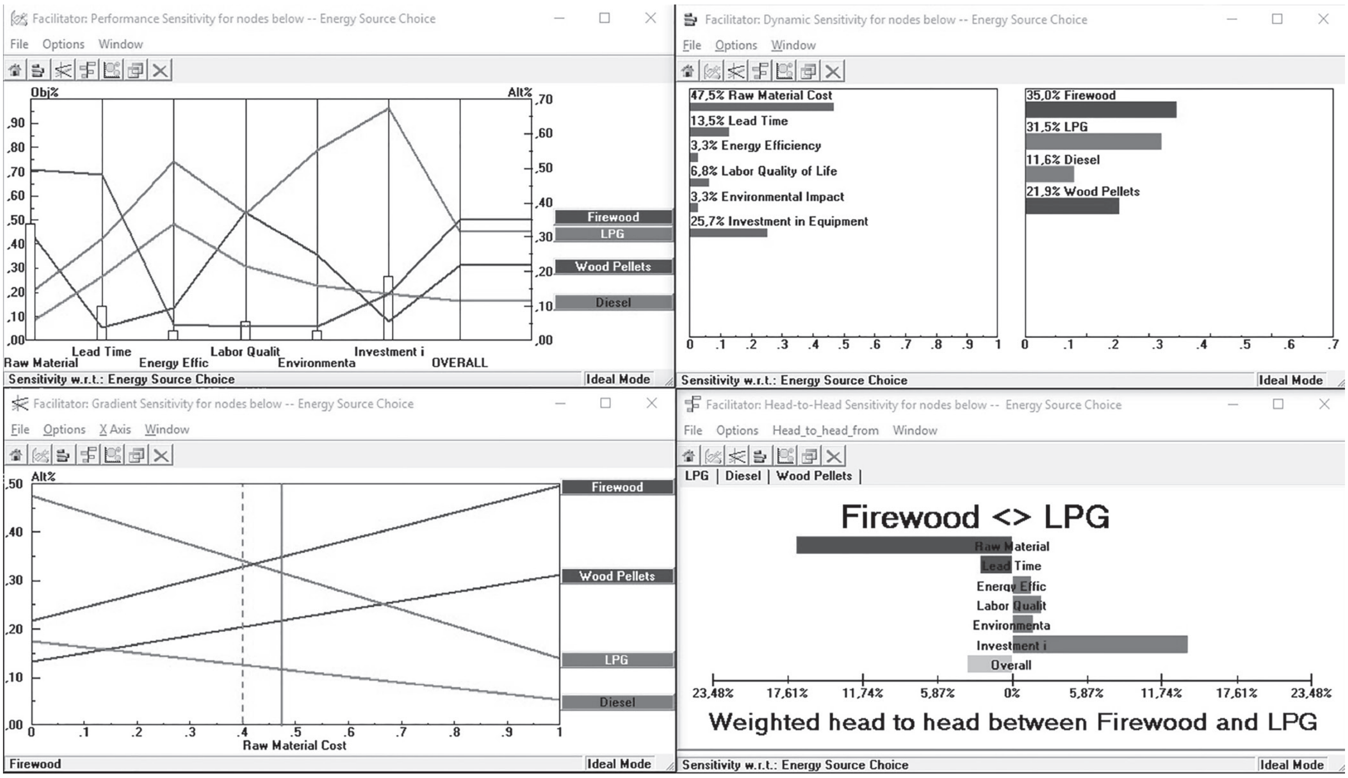

Figure 4 – Sensitivity relative to raw material price

CONCLUSIONS

According to the farmers' point of view, firewood was the preferred energy source. Liquefied petroleum gas was the second option. However, its priority value was close to that of firewood, and therefore both sources could be considered as alternatives with identical value. LPG demands low initial investments and allows better quality of life because it requires less labor effort, particularly in automated systems, whereas firewood presents the lowest cost.

The social-environmental criteria, including quality of life, energy efficiency, and environmental impacts, still have minor importance in decision-making by farmers on energy sources for broiler house heating. A limitation of the present study was not taking into account the possibility of using combinations of different energy sources that could provide a better alternative than choosing a single energy source. Finally, this model can be applied for solving similar decision-making problems of selecting energy sources for heat generation.

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