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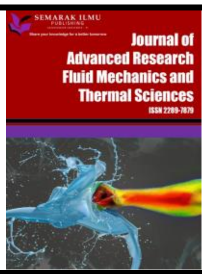

Economic and Competitiveness Analysis of Di-Amyl Ether as an Aviation Biofuel

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ABSTRACT

The main purpose of this article is to demonstrate and evaluate, through the survey of theoretical data, the practical applicability of biofuel competitiveness through the analysis of Di-Amyl Ether (DAE) to be used as aviation fuel. Therefore, in view of this, this research aims to analyze biofuel as a more sustainable option for energy sources in view of the reduction of pollutant emissions, with energy security, in addition to protecting and avoiding the degradation of the planet, as well as of natural resources. Therefore, the competitive analysis of biofuel portrays the potential for offering innovations to promote the sustainable development of the biofuel industry through the possibility of using inputs from ethanol. Thus, this paper demonstrates analyses of how to improve the competitiveness of aviation biofuels based on production and consumption, subsidize sustainable development and reduce the cost of production by reflecting on impacts on agribusiness.

1. Introduction

The practical applicability of biofuel competitiveness through the analysis of Di-Amyl Ether (DAE), to be used as aviation fuel, comprises an important challenge in energy production based on sustainable modes and efficiency applications. Given this, it is noteworthy to note that the production, conservation, as well as use of energy through efficient equipment and technologies are part of the research advancement to seek to optimize engineering and production in the face of energy efficiency in the use of bio-fuel for aviation by using Di-Amyl Ether (DAE) to design and optimize energy generation systems, as well as develop new devices to meet industrial demand. Therefore, this project can verify numerous innovative applications, mainly in the energy generation system, directed mainly to the aviation industry.

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Moreover, in this sense, the experimental and numerical results show that biofuels are more sustainable options of energy source that can be employed in the most diverse areas by reflecting the importance of competitiveness, the price of biofuels, and the impact on sustainability for the production chain. Therefore, the use of biofuel contemplates a solution to the problems involving energy decisions, system planning, and environmental projects since it is necessary to prioritize social criteria and environmental variables. Therefore, it is necessary to analyze competitiveness in the face of sectorial policies, the market structure, the governance structure, and the social context of management and competitive infrastructure of biofuel production in the agroindustrial chain. Because of this, it is possible to understand that the present research aims to help reduce gas emissions by developing an alternative energy source to replace oil. Given that there is too much need and demand for the expansion of energy sources in the face of the potential supply of innovations, with an adequate technological level for the sustainable development of the biofuel industry to assist the economic and social interests when elaborating strategic measures.

2. Methodology

2.1 Competitiveness in Biofuels

The three main principles guiding the trend toward renewable energy production are reduction of pollutant emissions, energy security, and also the need to protect against the degradation of the planet and its natural resources [1]. Biofuels are more sustainable energy sources that can be employed in various areas [2]. Developed research to evaluate the performance of several cooling systems for buildings and offices in urban areas, where they included, in addition to the old air-conditioning system, a new proposed technology integrated with biogas energy, which is a type of biofuel from organic source materials [3,4].

This energy source, which comes from organic matter, has been an alternative to replace fossil fuels, helping to reduce the emission of greenhouse gases [5]. Biofuels come from biomass and can replace this energy source [6]. In Brazil, the main biofuels in production and consumption are ethanol and biodiesel. Ethanol comes from sugarcane, and biodiesel is produced from vegetable oils or animal fats, which are then added to petroleum diesel in various proportions [7]. An understanding of the ethanol production chain is necessary to comprehend its complexity and all the factors that are part of it. A world pioneer, Brazil has about 18% of its fuel renewable. This position that the country has reached is desired by many countries seeking alternative energy sources to replace oil. From the 1970s to the present day, the national market has been a forerunner in ethanol consumption, being the country that most uses and produces this biofuel.

The complexity of the ethanol production chain in Brazil is because both the Northeastern and Southern models are typically formed by small and medium production units and are mainly associated with associative production and family agriculture. These types of resources change the profiles and relationships of the production chain, charging a greater understanding of the development of environmental, political, economic, social, ethical, and technological measures appropriate for the respective actions [8]. Concerning competitiveness in biofuels, it is observed that Brazil, in the long term, will pursue technological innovations to meet the demand for expansion of this energy source. This is restricted to traditional raw materials and the research of species with high biomass production capacity and high energy density, both for the production of ethanol, biodiesel, and biokerosene [9].

The search for sustainable technological innovation and its dependence on feedstock costs can influence biofuel prices and, consequently, its competitiveness in the market [9]. The international price of oil barrels is another important factor because if it continues at high price levels, the position of biofuels can improve in efficiency and competitiveness every year [10]. In addition, the existence of several centers, institutes, and companies of agricultural research in Brazil, make the country a potential granary of innovation supply, with an adequate technological level to act in the market of these fuels [11].

Different studies have addressed the importance of competitiveness, the price of biofuels, and sustainability for the production chain of this energy source. Among them is a study that sought to project future prices of raw materials, simulates production costs, and compares different biofuels and fossil fuels by scenario analysis [12]. Another study aimed to identify the critical success factors for promoting the sustainable development of the biofuels industry and helping stakeholders and decision-makers design the necessary strategic measures [13]. In addition, the research sought to analyze what organizational and managerial capabilities organizations can use to innovate for sustainability in producing such biofuels for aviation use [14].

The competitiveness drivers as shown in Figure 1, applied to the agroindustrial production chain according to the methodology proposed by César and Batalha [15] were: macroeconomic factors, technology, programs and sector policies, market structure, governance structure, productive resources, management, and infrastructure [16]. These eight competitiveness drivers and their application to the biodiesel production chain were studied to acquire the necessary knowledge to study the competitiveness of the di-amyl ether biofuel, this occurs because biofuel production presents inputs from ethanol, which in turn has a complex agro-industrial chain.

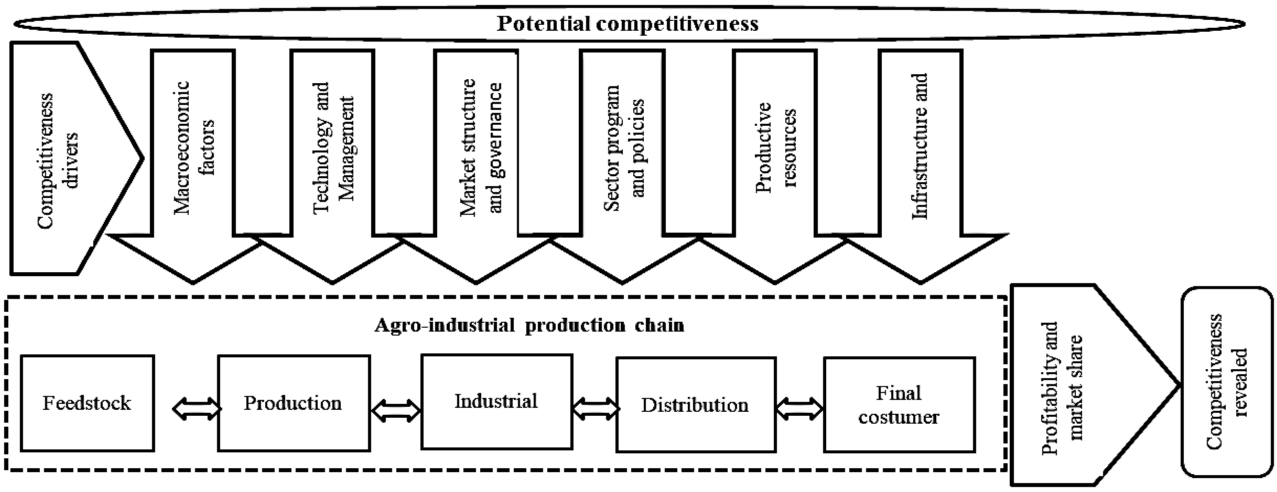

Fig. 1. Competitiveness drivers

Added to this, it was found that there is still no competitiveness analysis methodology in the literature exclusively for the biokerosene production chain. However, with this information alone, it would not be possible to analyze the competitiveness of di-amyl ether biofuel because other important variables impact the production of the compound. Thus, in the following topic, other elements that impact the competitiveness of biofuel production will be addressed: regulation and stakeholders.

2.2 Research Method

To better understand the steps this research followed, Figure 2 shows the flowchart of the paths taken to achieve the objectives. There will be four steps that go through the definition of the research scenario, the analyzed criteria, the proposed methods, and the analysis of the results.

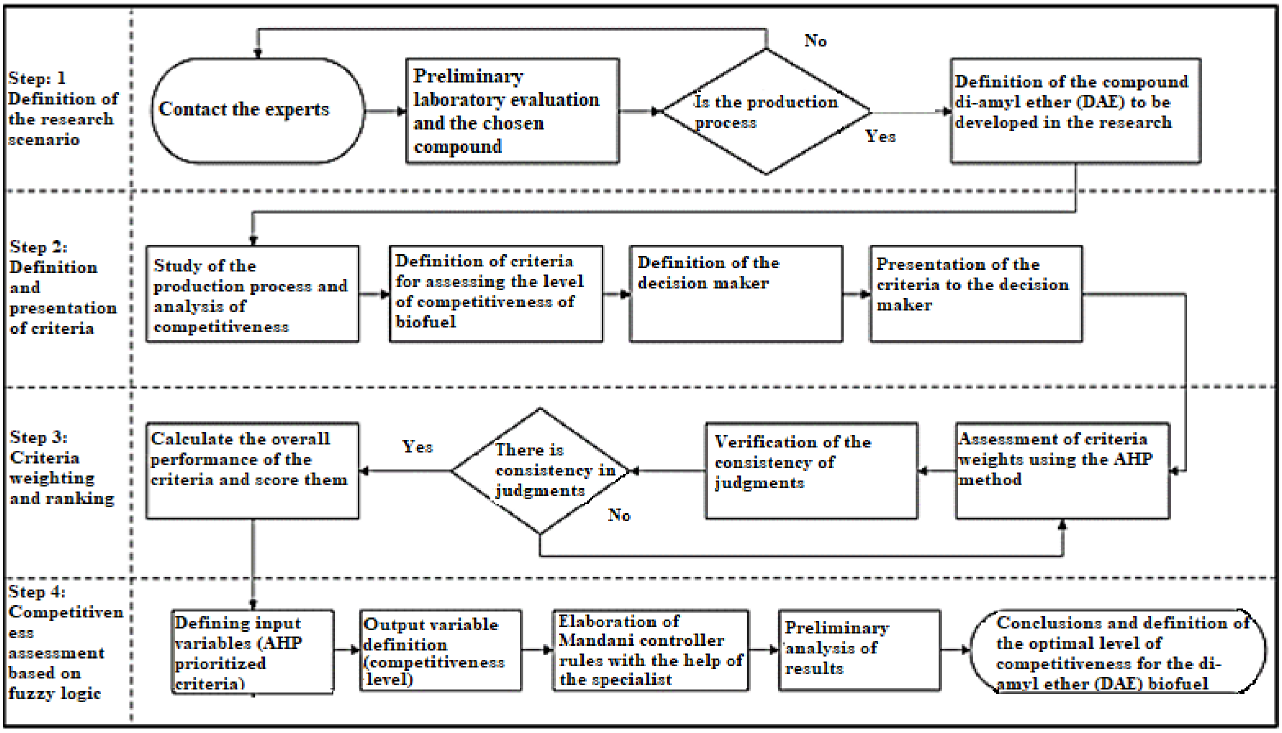

Fig. 2. Research flowchart

This research has gone through the four steps shown in the flow chart. Each of these steps will be more detailed from now on. In the next topics, the research scenario, the elaboration of the information collection instrument, and the methods that will evaluate the information will be presented. The study setting is the biomaterials laboratory in Porto Alegre, Rio Grande do Sul. The laboratory is dedicated to developing new renewable energy technologies using domestic raw materials. In addition, there is research on developing and optimizing transesterification and hydroesterification processes. Thus, this study collected the necessary information through contact with the researchers who developed and patented the Di-Amyl Ether compound (DAE) and biofuels experts.

The importance of analyzing the competitiveness of the compound is emphasized because it is the first step for the patented biofuel to begin to mature and attract the attention of investors and/or interested parties. The target audience that evaluated the study was defined through contacts at the laboratory that patented the biofuel. To this end, the survey information collection instrument was sent to five specialists (all with PhDs in the bioenergy field and more than ten years of experience in research in the area) who developed the compound and also to five people who have connections in research centers, foundations, and companies in the area of biofuels in Brazil, totaling ten respondents. After collecting the information, a simple average of the answers was made to evaluate the competitiveness of the biofuel studied following the study methods. Considering the information survey, it is necessary to classify how long the study phenomenon was analyzed. In the study, the cross-sectional survey method was used, i.e., a phenomenon was measured in a temporal cut of time, highlighting the characteristics presented at that moment of study [17]. In other words, all the characteristics of the Di-Amyl Ether compound (DAE) production in the competitiveness aspect were analyzed.

According to the information collection technique to analyze the defined phenomenon, a questionnaire was used involving various recommendations from regulatory agencies, research councils, stakeholders, and also the methodologies proposed by the authors, all of these described in the topics "competitiveness in biofuels" and "certifying agencies and stakeholders". This combination of information was necessary as there is no specific tool or case study that analyzes aviation biofuel competitiveness. Thus, because biokerosene production is still considered new, this research needed to seek information from already successful case studies involving the elements of competitiveness in other biofuels (ethanol and biodiesel). In addition, the recommendations proposed by experts in the biofuel field were analyzed to formalize the questionnaire. After studying all the information cited above, it was possible to design the research instrument.

The present questionnaire was inspired by the National Research Council (NRC) studies. This scientific organization produces and promotes the development of sustainable engineering with a focus on algae-based biofuels. Their experts recommend five criteria to evaluate biofuel development: energy consumption, system robustness, environmental impact, social acceptance, and economics [18]. Using this information as a starting point, it is possible to develop one's criteria that impact the competitiveness of the biofuel under study. It should be noted that the adaptation is necessary because it was not found in the literature an application of the criteria produced by the NRC in biofuels that are not based on algae. Thus, with the adaptation, the information collection tool was modeled on the research problem, reducing errors and inconsistencies that could occur, possibly better evaluating the Di-Amyl Ether (DAE) biofuel.

The AHP method is widely used when searching for solutions to problems involving energy decisions, system planning, and also environmental projects [19]. The AHP methodology contributed to the study as it prioritized the most critical criteria of the study problem after Fuzzy logic was applied to model the system. Then, in the fuzzy logic system, the most prioritized criteria were proposed as the input variables, and the output variable was competitiveness [20]. In the next topic, the reasoning steps of the AHP method are explained. First, it is necessary to create the hierarchical tree of the AHP method, built based on three blocks. The first block represents the robustness of the system, the second block social and economic acceptance, and finally, regulation and stakeholders. In these three proposed blocks, five criteria were created in each block. In Figure 3, the hierarchy of the study is presented.

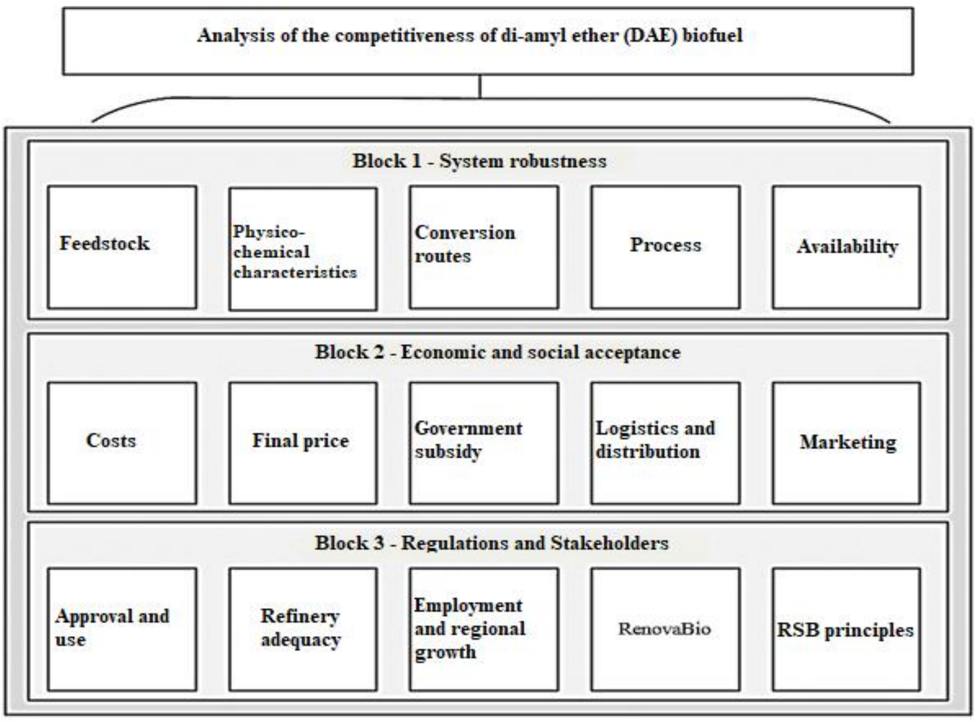

Fig. 3. Study hierarchy

The biofuel competitiveness analysis has fifteen criteria distributed over the three blocks. These criteria are all elements that can impact the level of competitiveness of the compound [21]. The formulation of these criteria was only possible after the studies on the competitiveness drivers measured in the topic added to the studies of the agencies and stakeholders. Thus, based on this information, the author elaborated the criteria shown in Figure 3. Table 1 presents the definition of all these criteria [22].

Table 1
Study criteria and definitions

Criteria	Definitions	Authors
Feedstock	(I)	Engelmann *et al.,* [23]
		Batista [24]
		Marques [25]
Physico-chemical characteristic	(II)	Cortez [26]
		Gonçalves *et al.,* [27]
		da Cruz *et al.,* [28]
		dos Santos Pereira *et al.,* [29]
Conversion routes	(III)	Cortez [26]
		da Cruz *et al.,* [28]
		Pereira *et al.,* [29]
		Cataluna *et al.,* [30]
Process	(IV)	da Cruz *et al.,* [28]
		Cataluna *et al.,* [30]
		Chong and Ng [31]
		Figueira *et al.,* [32]
		Missaggia *et al.,* [33]
Availability	(V)	Cortez [26]
		Figueira *et al.,* [32]
		Missaggia *et al.,* [33]
		Joshi and Singh [34]
Costs	(VI)	Fiorese *et al.,* [35]
		Filho *et al.,* [36]
		Guimarães [37]
		da Cruz and Damaso [38]
		Bartholomeu and Filho [39]
Final price	(VII)	da Cruz *et al.,* [28]
		Filho *et al.,* [36]
		Carbonell *et al.,* [40]
		Pérez *et al.,* [41]
		Ribeiro *et al.,* [42]
Government subsidy	(VIII)	Cataluna *et al.,* [30]
		Missaggia *et al.,* [33]
		Joshi and Singh [34]
		Hasan [43]
		Caetano *et al.,* [44]
Logistics and distribution	(IX)	Bartholomeu and Filho [39]
		Carbonell *et al.,* [40]
		Chaves and Gomes [45]
		Branco [46]
Marketing	(X)	Missaggia *et al.,* [33]
		Caetano *et al.,* [44]
		Pepall *et al.,* [47]
Approval and use	(XI)	Grangeia *et al.,* [48]
		Ioris [49]
Refinery adequacy	(XII)	Chaves and Gomes [45]

Employment and government growth	(XIII)	Branco [46] Grangeia and Santos [50] Chaves and Gomes [45] Grangeia *et al.,* [48] de Carvalho *et al.,* [51]
RenovaBio	(XIV)	Prado *et al.,* [16] Marques [25] Saaty [52]
RSB Principles	(XV)	Pepall *et al.,* [47] Grangeia *et al.,* [48] Ioris [49] Grangeia and Santos [50]

Note: The table displays the criteria, definitions and authors columns. In the definition's column, items (I, II, III, IV, V, VI, VII, VIII, IX, X, XI, XII, XIII, XIV, XV), are described in the text.

In Table 1: Criteria Feedstock (I), it comprises the choice of input necessary for the production of biofuel. Biomass is all organic matter used to produce clean energy. For example, sugarcane, castor beans, soybeans, canola, and algae, among other raw materials, can be used to produce biokerosene. Criteria Physico-chemical characteristic (II) A biofuel needs to have physicochemical characteristics similar to traditional aviation kerosene (QAV-1) to be blended and used in aircraft turbines. The technical standards established by the American Society for Testing and Materials (ASTM); Energy Institute (IP), and nationally by the National Petroleum Agency (ANP) set standards for the following characteristics: appearance, composition, volatility, fluidity, combustion, corrosion, stability, contaminants, conductivity, lubricity, and mixture percentage. Criteria conversion routes (III) This criterion comprises the importance of choosing the production route. There are five American Society for Testing and Materials (ASTM) approved routes for biofuel production. Fischer-Tropsch (FT); Hydroprocessed esters and fatty acids (HEFA); Alcohol (isobutanol) to jet (ATJ); Alcohol (ethanol) to jet (ATJ) and Synthesized iso-paraffins (SIP). Criteria Process (IV) For biofuel production, a standardized production system must be in place. Ensuring the reliability of chemical processes is important so that the final product has constant high quality, regardless of production scale.

Criteria Availability (V) This criterion represents the production scale, which guarantees that a given production volume is met. The production of biofuel must not suffer interruptions because to serve the aircraft, there must be continuous production. Availability comprises the final product and intermediate inputs throughout the production system (growing raw materials, inputs, production, and final product). Criteria Costs (VI) This criterion comprises the costs: project, equipment, inputs, taxes, and other elements representing financial obstacles to producing biofuel on a viable scale. Criteria Final price (VII) This criterion represents the price per liter that the biofuel is sold. Furthermore, it is taken into account that the price per liter of biokerosene is compared to traditional aviation kerosene (QAV-1). Criteria Government subsidy (VIII) This criterion represents the degree of government incentive to promote the technology: tax incentives, public policies, regulations, and public-private partnerships. Criteria Logistics and distribution (IX) It represents the biofuel distribution chain so that the final product reaches customers. It is a logistics that collects and distributes biofuel from origin to destination.

Criteria Marketing (X) It evaluates the degree of acceptability and the difficulties in commercializing biofuel in a market dominated by fossil fuels. It is known that biofuel competes with the fossil fuel industry, which has been active for a century. Criteria Approval and use (XI) Evaluates the degree of importance of homologating and being able to use biofuel. The National Petroleum Agency (ANP) establishes several regulations and tests for a biofuel to be certified and marketed nationally. Criteria Refinery adequacy (XII) This criterion includes a possible adaptation of production plants already in operation to produce biofuel—new equipment and expansions, among other elements that may be needed for production. Criteria Employment and government growth (XIII) This criterion assesses the expansion of jobs and regional economic development. Criteria RenovaBio (XIV) RenovaBio is part of the national biofuels program. A policy to help define energy security and greenhouse gas emission reduction strategies. Thus, this criterion represents the importance of this program for developing biokerosene. Criteria RSB Principles (XV) The Roundtable Sustainable Biomaterials (RSB) principles and criteria describe how to produce biomass, biofuels, and biomaterials in a socially and economically viable way. In total, there are 12 principles and criteria that, if met, receive the international certificate. The 12 criteria are Legality, Continuous improvement, GHG emissions, Human and labor rights, Local food security, Rural, and social development, Conservation, Ground, Water, Air Quality, Technology, and arable area. Thus, this criterion assesses the importance of these elements for biofuel production.

After elaborating the hierarchy of the study and defining all the criteria that will be evaluated by the AHP method, the next topic is to describe the steps of the AHP method [21]. The AHP method divides the problem into hierarchical levels for better understanding and evaluation. A hierarchy is created to describe the studied problem, starting with the global objective and then segmented into parts, criteria, n-subcriteria, and alternatives [22]. The pairwise comparison converts qualitative information into quantitative information using Saaty's scale to make judgments [51]. Saaty scale values comprise 1 to 9 points and their reciprocals. This scale helps to evaluate the degree of importance of the analyzed information. Right below, there is Table 2 to demonstrate this issue.

Table 2
Saaty scale

Scale	Assessment	Reciprocal
Preferred to the extreme	9	1/9
Very strong to extreme	8	1/8
Very strong preferred	7	1/7
Strong to very strong	6	1/6
Strongly preferred	5	1/5
Moderate to strong	4	1/4
Moderately preferred	3	1/3
Equal to moderate	2	1/2
Equally preferred	1	1

After the pairwise evaluation using the values shown in Table 2, the consistency analysis of the information collected was performed using the calculations of the consistency ratio (CR), the consistency index (CI), and the random index (RI) according to Eq. (1).

$$CR = \frac{CI}{RI} \quad (1)$$

In addition, for the t calculation developmen, it is necessary to stipulate the CI, calculated by Eq. (2), where the λmax results from the multiplication of the sum of the columns of the matrix and the priority vector.

$$CI = \frac{\lambda_{max}}{n-1} \quad (2)$$

Saaty stipulated the random index, and the value to be considered is the one concerning the size of the evaluation matrix, as presented in Table 3.

Table 3
Random index

Matrix dimension	1	2	3	4	5	6	7	8	9	10	11	12	‘13
Random inconsistency	0	0	0,58	0,9	1,12	1,24	1,32	1,14	1,45	1,49	1,51	1,48	1,56

To make an admissible matrix, the survey must have an IR with a consistency ratio of less than or equal to 10%. The Saaty scale, with its 9 points and reciprocals, was used to judge the information. The weights 3, 5, 7, and 9 are the order of magnitude for the pairwise comparison. The weights 2, 4, 6, and 8 are the intermediate values, and weight 1 is the equal importance value. These weights made it possible to compare the study criteria pair by pair.

2.3 Fuzzy Logic Approach

For modeling, the system based on fuzzy logic will be used the criteria prioritized by the AHP method. The MATLAB® software through the Fuzzy Logic Toolbox module was used to model the system. It is noteworthy that the system structure was constructed in triangular function, based on the following rules: knowledge base, fuzzifier, inference method, and a defuzzifier. Figure 4 demonstrates the input variables of the model and the output variable.

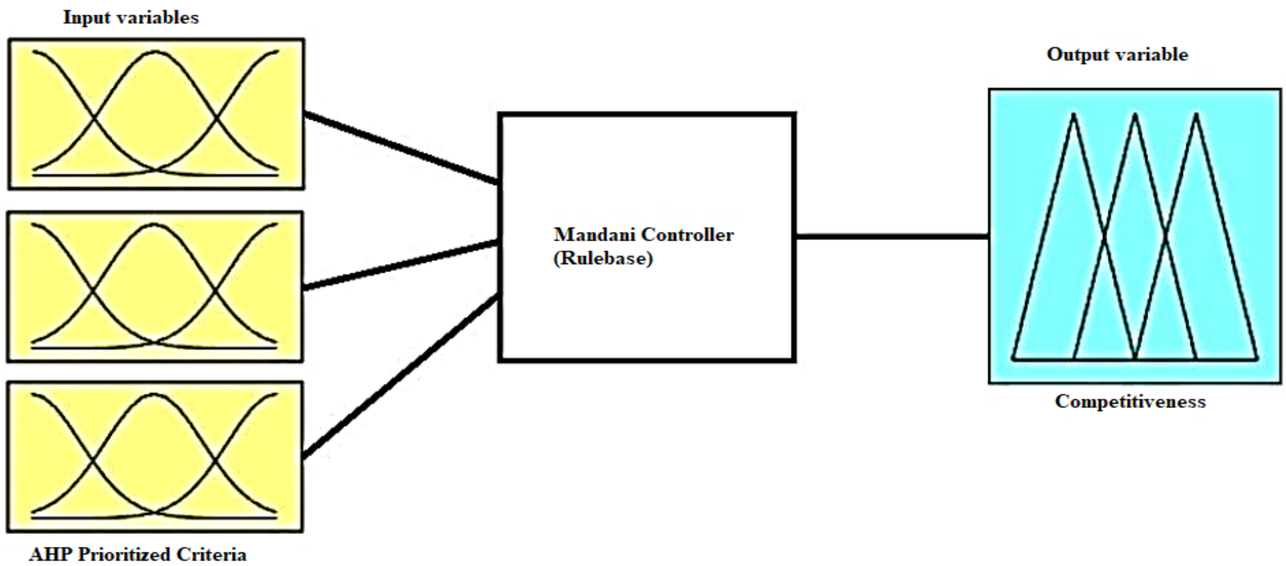

Fig. 4. Fuzzy variables

The number of input variables was defined so that after applying the AHP method, the criteria with the highest degree of importance would be selected to compose the fuzzy input variables. The experts defined the range domains of the variables. In addition, the construction of the Fuzzy sets was, in triangular function, with three linguistic characteristics. These were estimated based on the classification relative to the state of the system in each of the variables, with the ranges set at 0, 40, 60, and 100. Figure 5 presents the four functions of the system because some of the analyzed criteria have different linguistic characteristics [52].

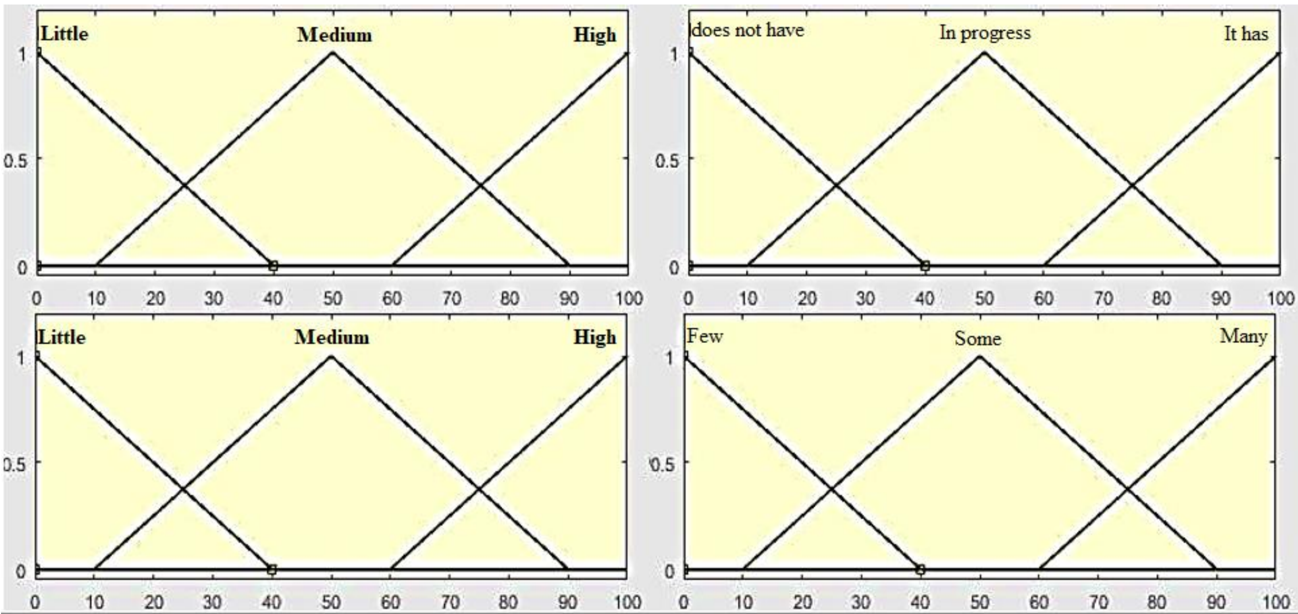

Fig. 5. Triangular functions

The different variable state nomenclature is just an adaptation for the variable language. The results of the defuzzification were calculated using the center of gravity method, also used by Perissinotto *et al.,* [53]. Thus, with the application of fuzzy logic, it is possible to define a balance point in the analysis of biofuel competitiveness, indicating which are the lowest levels of the input variables required to maintain a minimum level of competitiveness acceptable for the production of the compound [54]. The respondents also defined creating the rule base for the fuzzy module.

3. Results

In this section, the results of the study are presented and discussed. The results are organized in three sections, according to the AHP method and Fuzzy Logic.

3.1 AHP Development

After defining the criteria and creating the study hierarchy, the next step is the construction of the pairwise comparison matrices and the definition of the priority vectors of each criterion. At this point, the decision maker performs the evaluations and calculates the vectors for each criterion [21]. The comparison matrix is represented in Table 4 and Table 5, and Figure 6 shows the normalized vectors.

Table 4
Triangular functions

Criteria	Cr1	Cr2	Cr3	Cr4	Cr5	Cr6	Cr7	Cr8	Cr9	Cr10	Cr11	Cr12	Cr13	Cr14	Cr15
Cr1	1	3	3	3	1	5	1	3	7	1	5	5	1	1	1
Cr2	1/3	1	1	1	1/3	3	1/3	1	5	1/3	3	3	1/3	1/3	1/3
Cr3	1/3	1	1	1	1/3	3	1/3	1	5	1/3	3	3	1/3	1/3	1/3
Cr4	1/3	1	1	1	1/3	3	1/3	1	5	1/3	3	3	1/3	1/3	1/3
Cr5	1	3	3	3	1	5	1	3	7	1	5	5	1	1	1
Cr6	1/5	1/3	13	13	1/5	1	1/5	1/3	3	1/5	1	1	1/5	1/5	1/5
Cr7	1	3	3	3	1	5	1	3	7	1	5	5	1	1	1
Cr8	1/3	1	1	1	1/3	3	1/3	1	5	1/3	3	3	1/3	1/3	1/3
Cr9	1/7	1/5	1/5	1/5	1/7	1/3	1/7	1/5	1	1/7	1/3	1/3	1/7	1/7	1/7
Cr10	1	3	3	3	1	5	1	3	7	1	5	5	1	1	1
Cr11	1/5	1/3	1/3	1/3	1/5	1	1/5	1/3	3	1/5	1	1	1/5	1/5	1/5
Cr12	1/5	1/3	1/3	1/3	1/5	1	1/5	1/3	3	1/5	1	1	1/5	1/5	1/5
Cr13	1	3	3	3	1	5	1	3	7	1	5	5	1	1	1
Cr14	1	3	3	3	1	5	1	3	7	1	5	5	1	1	1
Cr15	1	3	3	3	1	5	1	3	7	1	5	5	1	1	1
TOTAL	9	26	26	26	9	50	9	26	79	9	50	50	9	9	9

Note: In Table 4, the total of criterion 2 (Cr2), criterion 3 (Cr3), criterion 4 (Cr4), and criterion 8 (Cr8) is 26 and corresponds to 1/5. The total of criterion 6 (Cr6), criterion 11 (Cr11) and criterion 12 is 50 and corresponds to 1/3

Table 5
Eigenvalue and normalized vector

c	SELF VALUE	STANDARDEZED VECTOR
Cr1	2,11	11%
Cr2	0,83	4%
Cr3	0,83	4%
Cr4	0,83	4%
Cr5	2,11	11%
Cr6	0,38	2%
Cr7	2,11	11%
Cr8	0,83	4%
Cr9	0,21	1%
Cr10	2,11	11%
Cr11	0,38	2%
Cr12	0,38	2%
Cr13	2,11	11%
Cr14	2,11	11%
Cr15	2,11	11%
TOTAL	19,41	100%

After all the calculations, it is already possible to know which criteria were given the most weight in the AHP method. According to the method, there was a tie in seven criteria, i.e., the same value of the degree of importance. Thus, the seven tied criteria were analyzed: Cr1, Cr5, Cr7, Cr10, Cr13, Cr14, and Cr15. These seven criteria represent respectively: Raw material; Availability; Costs; Employment and regional growth; Homologation and utilization; RenovaBio; and RSB Principles.

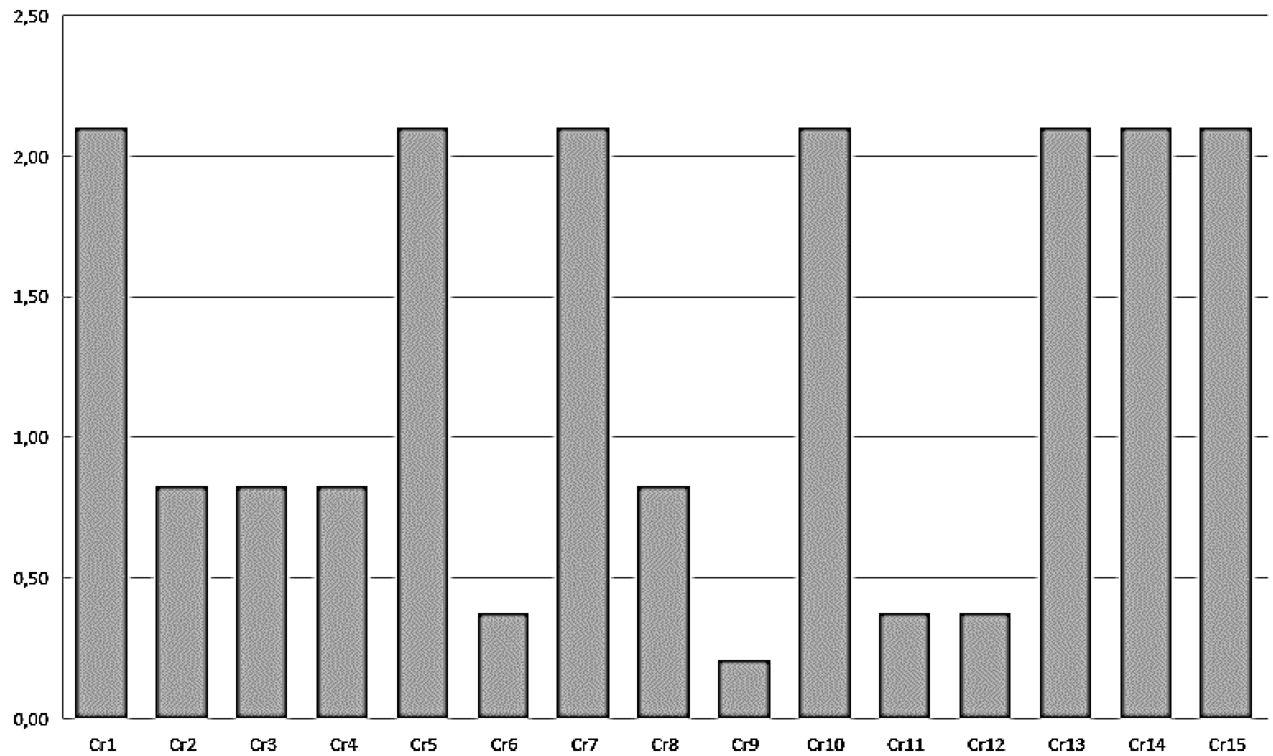

Fig. 6. Prioritized criteria

The graph above illustrates the results of the application of the AHP method. The analysis of the degree of importance of each criterion translates into the decision-making of the specialists concerning the influence of competitiveness. Moreover, the analysis of the judgments allows translating the previously qualitative information into quantitative ones.

Now it is necessary to analyze if there is consistency in the information found. These indexes below verify if there is consistency in the answers that the decision maker attributed. The calculation of the indexes follows the methodology proposed by Saaty [52]. Table 6 shows the consistency indices of the answers.

Table 6
Prioritized criteria

Indexes	Values
λ_{max}	15,18
Consistency index (IC)	0,013
Consistency reason (RC)	0,008

According to the model consistency indices, the CI was calculated as 0.013. Saaty determines that for consistency in the answers, the CI value found must be CI ≤ 0.10. So, there is consistency in the decision maker's answers. The next step is to start the fuzzy logic by having the seven criteria prioritized by the AHP method as a starting point.

3.1.1 Fuzzy logic approach

The human mind does not reason in a binary way (0 or 1) but with an infinity of options where there is little existence of accuracy and absolute truth [55]. In Fuzzy theory, there is the possibility that a statement may not be completely true or completely false, and there may be intervals on a continuous scale because Fuzzy is based on an interval scale, where numbers can have a range of

[0;1]. Thus, the Fuzzy approach helps to fill the gaps that various classical methods have not completed [56].

The fuzzy system starts with the optimization strategy of the input variables so that the desired value does not interfere with competitiveness. The optimal points of each variable are quantified and determined for each class. Thus, the definition of each variable and the linguistic values are demonstrated in Table 7 and Table 8.

Table 7
Definition of variables

Variables		Linguistic characterization	Definition
Input	Feedstock	Few	Raw material for an average production of 10 m³ of biofuel.
		Average	Raw material for an average production of 15 m³ of biofuel.
		High	Raw material for an average production of 20 m³ of biofuel.
	Availability	Short	Product must meet around 25 flight hours/month.
		Medium	Product must meet around 37 flight hours/month.
		High	Product must meet around 50 flight hours/month.
	Costs	Short	Monthly fuel cost for the manager around R$55,000/aircraft.
		Medium	Monthly fuel cost for the manager around R$ 82 thousand/aircraft.
		High	Monthly fuel cost for the manager around R$ 110 thousand/aircraft.
	Employment and regional growth	Short	1% increase in jobs offered in the annual production chain.
		Medium	5% increase in jobs offered in the annual production chain.
		High	10% increase in jobs offered in the annual production chain.
	Approval and use	Does not have	Does not meet ATSM and ANP regulations.
		In progress	Meets some regulations defined by ATSM and ANP.
		It has	Meets all ATSM and ANP regulations.
	RenovaBio	Short	Does not meet program values.
		Medium	It has approximation with some program values.
		High	It presents a closer approximation to the program values.
	RSB Principles	Few	Less than 4 principles met.
		Some	Around 6 principles met.
		Many	More than 9 principles met.
Exit	Competitiveness	Low	Biofuel is 20% less competitive.
		Average	Biofuel is 50% ≤ x ≤60% competitive.
		High	Biofuel is 60% more competitive.

In Fuzzy, the control variables assume individual values, incorporating the trends. The expert defines the rules that will vary the control variables across all possible cases in each strategy—for example, a case, (Raw Material and Availability) = (Medium and Low).

The specialist must answer: what can happen with competitiveness if the raw material is average and the availability is low? The selected case offers the solutions, and the specialist confirms or modifies one of the rules in some of the control variables. In the example above, the expert may advise: purchasing more raw materials for production and producing more to meet demand and improve product availability.

Table 8
Range Domains

Variables		Linguistic characterization	Range domains
Input	Feedstock	Few	0 - 0 - 40
		Average	10 - 50 – 90
		High	60 -100 - 100
	Availability	Short	0 - 0 - 40
		Medium	10 - 50 - 90
		High	60 -100 - 100
	Costs	Short	0 - 0 - 40
		Medium	10 - 50 - 90
		High	60 -100 - 100
	Employment and regional growth	Short	0 - 0 - 40
		Medium	10 - 50 - 90
		High	60 -100 - 100
	Approval and use	Does not have	0 - 0 - 40
		In progress	10 - 50 - 90
		It has	60 -100 - 100
	RenovaBio	Short	0 - 0 - 40
		Medium	10 - 50 - 90
		High	60 -100 - 100
	RSB Principles	Few	0 - 0 - 40
		Some	10 - 50 - 90
		Many	60 -100 - 100
Exit	Competitiveness	Low	0 - 0 - 40
		Average	10 - 50 - 90
		High	60 -100 - 100

With the help of the MATLAB® software, it was possible to simulate several situations among the input variables respecting the rules. Thus, the software simulated twenty possible events representing the various situations between the input variables (seven criteria) and the results found in the output variable (competitiveness). These rules were created through contact with the laboratory managers who patented the compound. Thus, a responsible person was designated, considered by the laboratory, with greater knowledge to formulate the base events. In Figure 7 are the twenty rule bases.

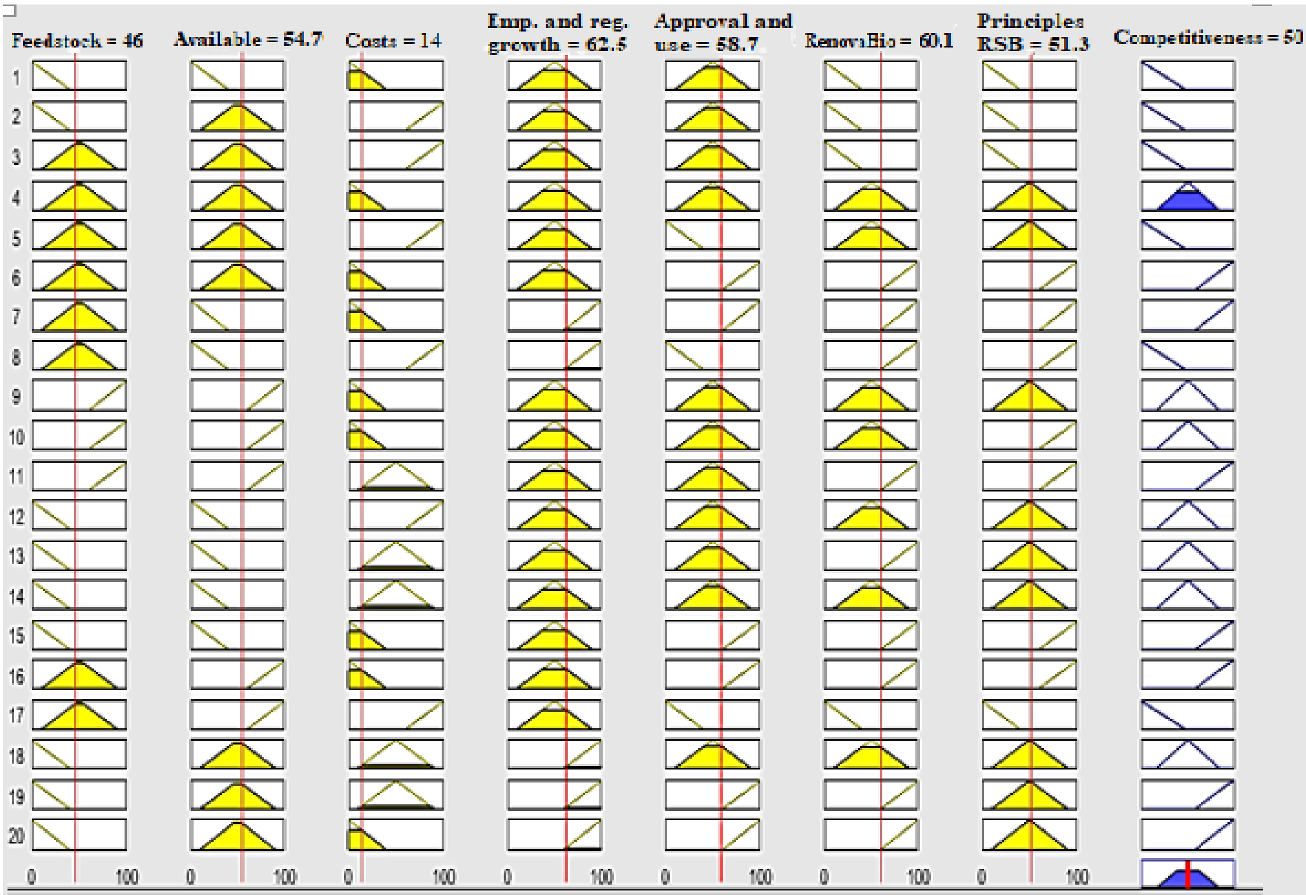

Fig. 7. Rule base

The figure above demonstrates the state estimation of competitiveness as a function of the seven input variables. Through the twenty rule bases above and inference in the Mamdani controller, it is possible to find the equilibrium point of the input variables so that minimum competitiveness of the di-amyl ether biofuel is maintained. By fine-tuning the variables and respecting the possible events, it is possible to find the best level of competitiveness.

It is emphasized that this study used Fuzzy logic to model the system because, according to McAllister [57], some characteristics of systems are beneficial to applying Fuzzy logic. For Example, decision support systems, systems that use the expert approach (humans with the domain of the problem or even other sources of knowledge), and systems with many variables that are difficult to model [58]. These are the main domain characteristics of this study [59]. Thus, the Fuzzy system was a suitable choice to model and evaluate the problem. The following topics are demonstrated: the interpretation of the information from the Fuzzy Logic, discussion of the results, and future perspectives for the alternative energy sector.

3.1.2 Implementation and proposed actions

The AHP method and fuzzy logic were used to analyze the competitiveness of Di-Amyl Ether (DAE) biofuel. With the help of experts, the AHP method prioritized the seven criteria with the highest degree of importance out of fifteen, respectively: Raw material; Availability; Costs; Employment and regional growth; Approval and use; RenovaBio; and RSB Principles. The seven prioritized criteria were inserted into the fuzzy logic as input variables, and the output variable was competitiveness. Through expert help, twenty rule bases were created, after which the Mamdani controller simulated the possible events and presented the biofuel competitiveness level.

The best biofuel competitiveness level found by the system was 50 (medium). The sensitivity analysis of the seven input variables made it possible to find the criteria that impact a better or worse competitiveness level. This analysis resulted in three criteria: Costs, Homologation and utilization, and RenovaBio.

The sensitivity test of the variables was carried out in the MATLAB® software through the Fuzzy Logic Toolbox module to discover possible oscillations in the competitiveness level. Thus, when the test was carried out, it was possible to see that the criterion "Costs" presented the highest sensitivity to oscillations in the level of competitiveness of the compound. When analyzing this isolated variable, competitiveness can rise or fall (10%), and the best value found for this criterion was 14 (low). For better understanding, the best interval of the variables that resulted in the best level of competitiveness and the definition of the variables will be shown in Table 9.

Table 9
Interpretation of fuzzy logic results

Variables		Best result		Interpretation
Input	Feedstock	Average	46	Raw material for an average production of 15 m³ of final product
	Availability	Medium	54,6	Product must meet around 37 flight hours/month
	Costs	Short	14	Monthly fuel cost for the manager around R$ 55 thousand/aircraft
	Employment and regional growth	Medium	62,5	5% increase in jobs offered in the annual production chain
	Approval and use	It has	58,7	Meet all ATSM and ANP regulations
	RenovaBio	Medium	61,1	Approximation with some program values
	RSB Principles	Some	51,3	Around 6 principles met
Exit	Competitiveness	Average	50	Biofuel has a satisfactory level of competitiveness

The Di-Amyl Ether biofuel (DAE), according to the evaluated criteria, showed a satisfactory level of competitiveness. Of the seven criteria evaluated, Costs, Homologation and utilization, and RenovaBio are the most sensitive for increasing or decreasing competitiveness. Thus, for biofuel to present greater competitiveness in the market, it is suggested that the specialist prioritize his efforts in meeting these criteria.

When comparing the results found by this study with the competitiveness drivers of the production chain of biodiesel in Chong and Ng [31], it is possible to affirm that the productive resources and the programs and public policies are the drivers that have more impact on the best competitiveness of the biofuel Di-Amyl Ether (DAE). However, in the study by Figueira and Galache [32], a competitiveness driver had more impact on the biodiesel chain segment: programs and public policies. This comparison of results is interesting as it confirms the importance of public policies for developing and expanding technology in the clean energy sector.

Thus, it can be stated that for the success of di-amyl ether biofuel in the domestic market, maximum approximation in incentive programs, such as RenovaBio, is necessary. Furthermore, considering the criteria that the experts defined for this study, it can be stated that the biofuel studied is competitive and meets the criteria necessary to be an aviation biofuel. However, given the complexity of the energy sector, biofuel can be competitive and not necessarily be the official biofuel in the Brazilian energy matrix because other research develops biofuel for the same purpose but with other raw materials. So, it is possible that the official biofuel for aviation, being incorporated into the national energy matrix, will be the one that comes closest to the requirements and interests of the national biofuel program - RenovaBio.

In the next topic, the results from other perspectives will be discussed, and the reality of aviation biofuels in the national context is also analyzed.

3.1.3 Discussion of results and future perspectives

Some comments are worth highlighting by analyzing the results found with the reality that the aviation fuel sector finds itself today [24]. Meeting the growth in demand for air transport and concomitantly minimizing the impacts of greenhouse gas emissions in the short and medium term is only possible through the production and use of biofuels [60].

The results found in the study corroborate the reality of the aviation biofuels sector in Brazil. For the healthy expansion of the sector, it is necessary to solve two main barriers: a decrease in the high production cost of aviation biofuels compared to aviation kerosene, concomitant the effective implementation of policies that determine the use of biofuels for air transport [61]. After applying the methods of the study, it has already been found that the compound Di-Amyl Ether (DAE) is competitive and has the potential to be used as aviation fuel.

The following analyses will be discussed in more depth on the following topics: physicochemical characteristics, production costs, and policy measures [62]. These characteristics were considered important by the experts and also by the author.

3.1.4 Physicochemical characteristics

The composition of DAE showed 98% purity. Moreover, when combined with QAV-1 in formulations of (10DAE, 20DAE, and 30DAE), the compound showed decreased freezing point and increased oxidation reaction rate, which is already a good indication for use as aviation fuel. Table 8 and Table 9 show some results found in the laboratory tests [30].

In Table 10, when comparing Di-Amyl Ether (DAE) with traditional aviation kerosene (QAV-1), it is observed that the melting, boiling, ignition, and freezing points are more advantageous for DAE. This advantage is already considered a competitive differential because it allows for greater safety in flight operations. For example, the QAV-1 freezes much earlier than the DAE, becoming inoperable at temperatures above -47 º C. The same reasoning applies to the melting point.

Table 10
QAV-1 and DAE physicochemical results

Parameter	DAE	QAV-1	Unit
Fusion point	-120	-115	ºC
Initial boiling point	142,3	163,1	ºC
Flash point	52	58	ºC
Freezing point	-92	-47	ºC

Table 11 shows the results of the tests when the DAE compound was mixed in fractions of 10, 20, and 30% to QAV-1 as required by the ATSM and ANP.

Table 11
Test results in formulations

Parameter	10DAE	20DAE	30DAE	Unit
initial boiling point	133,8	135,1	140,7	ºC
Density at 20ºC	0,823	0,819	0,811	g/cm^{-3}
Freezing point	-57	-62	-68	ºC

In Table 11, it can also be seen that when combined in different fractions, the values found for the parameters, for example, boiling and freezing remain high. Moreover, according to Cataluna *et al.,* [30], Di-Amyl Ether (DAE) is compatible and meets the technical specifications of a biofuel.

Thus, it is suggested that due to the physicochemical characteristics presented, it could be used both in domestic aviation and also in military operations. For example, military aircraft flying at high altitudes or near the poles of the earth operate in very harsh environments requiring a safe operation. In these situations, the temperatures are extreme, but the DAE biofuel would remain operational, ensuring greater safety than QAV-1. So, considering the physicochemical criteria, the compound is very competitive and can perform in different modes of operation (civil or military aviation).

3.1.5 Production costs

The competitiveness of Di-Amyl Ether (DAE) biofuel will also depend on its production cost relative to fossil kerosene. Fuel cost is the largest indirect expense for airlines, which is 22% of direct costs on average [63].

Aviation biofuels, such as di-amyl ether, are already a technically feasible alternative when the goal is to reduce pollutant emissions. However, when production and distribution costs are considered, it loses out to petroleum derivatives, making it unviable because production processes exist in agricultural and industrial chains. Thus, considering the whole, the compost production process is complex and costly. From an economic standpoint, its viability may occur when new increases in international oil prices occur, which is considered possible in a medium to long-term scenario (political instability in the oil-producing zones, accelerated growth in consumption, among other things).

The di-amyl ether biofuel presents as sustainable input isoamyl alcohol from ethanol distillation. Ethanol production in Brazil is based on sugarcane. So, it is observed that the production chains are interconnected and that a fraction of ethanol is needed to produce the di-amyl ether compound. This need for input from another production chain can impact production cost oscillation. The other input, hydrocarbon cut C5, obtained by cracking petroleum naphtha, originates from the direct distillation of petroleum itself into lighter fractions. This input is likely less costly than the previous one due to the shortening of the production process chain.

Biofuels, in their totality, obtain their raw material from biomass. Therefore, a possible way to minimize production costs would be the implementation of refineries designed for continuous production. In addition, new research can unlock the potential of other inputs, for example, solid and agricultural waste. It is then possible that production costs could be lowered because these raw materials are generally abundant and cost less.

3.1.6 Political measures

Finally, the most crucial factor for biofuel progress is policy measures in the sector. RenovaBio is an excellent program that could boost the production and use of biofuels in aviation and also in other transport sectors. However, without a favorable policy scenario, it is unlikely that biofuels will grow in consumption and be more competitive than fossil fuels. Subsidizing and supporting the development of the sector also includes reducing the financial risks for investments in refining projects and measures for consumption compliance, among other mechanisms that can lower the production cost of biofuels.

Policy measures will be essential to stimulate sustainable aviation. The United States and European Union countries have already established the policy mechanisms that will support the use of biofuels in aviation in the coming years. In Brazil, through RenovaBio, the same is expected to happen. In this way, the production of alternative fuels in aviation can gain confidence and greater competitiveness over the years.

4. Conclusions

The study applied methods adapted to the context of analysis of competitiveness in the field of biofuels. The techniques presented were combined into a tool that helps specialists interpret the function and better understand decision-making. The methodologies for analyzing the competitiveness of already successful biofuels (ethanol and biodiesel), competitiveness drivers, stakeholders, and certifying agencies contributed to making it possible to create their assessment tool. The main advantage of using the techniques and studies of experts in bioenergy and biofuels, in addition to being efficient in the results, when combined with a multi-criteria method, is to amplify success in decision-making.

The bibliometric analysis made it possible to discover in the literature how the methods used in this research were used by the authors and also how they behaved in different situations. The deficiencies, difficulties, and paths reported by the authors made it possible to acquire more knowledge on the topic and adjust the study. Thus, in a general analysis of the literature, this study brought the application of the methods innovatively and objectively in aviation biofuels since the competitiveness analysis in this context is still considered new. It has ample space for research and development in a constantly expanding market with a need for research, development, and production of alternative fuels.

Given the objectives of this study, it can be said that they were met. Through the literature review, it was possible to discover the development of research on biofuels in Brazil and the world. The study of this information made it possible to develop, in an evaluation tool, the criteria that influence the competitiveness of the di-amyl ether biofuel. Contacting experts in the area made it possible to test the study tool and present the results. The AHP method contributed to the prioritization of the most critical criteria in the Di-Amyl Ether (DAE) biofuel production process, in terms of importance, respectively: Raw material; Availability; costs; Employment and regional growth; Approval and use; RenovaBio; and RSB Principles. The Fuzzy logic demonstrated the minimum levels necessary for the generated competitiveness to be in accordance with the reality of the biofuels market. In addition, of the seven criteria evaluated, the criteria: Costs, Approval and use, and RenovaBio, are the most impactful in terms of increasing or decreasing competitiveness.

These three criteria (Costs, Homologation and use, and RenovaBio) were the ones that most interfered with a better or worse level of competitiveness of the di-amyl ether biofuel. It should be noted that the Cost criterion was the one that showed the most sensitivity to the increase or decrease (10%) in the competitiveness of the compound. In short, the applied methods showed that biofuel has satisfactory competitiveness (50%) and has the potential to be used as aviation biofuel. The reasons for this statement will be discussed in the following paragraphs.

The Di-Amyl Ether (DAE) biofuel presented interesting physicochemical characteristics for potential aviation biofuel. In laboratory tests, when mixed with QAV-1 in 10DAE, 20DAE, and 30DAE fractions, the compound showed more advantageous levels of melting, boiling, inflammation, and freezing points for DAE compared to traditional aviation kerosene, configuring a high competitive differential in terms of operation and safety (system robustness). The relationship between the evaluation of the system and the aid in decision-making proposed by the study was essential to analyze the level of competitiveness of the biofuel Di-Amyl Ether (DAE). In this way, it was possible to contribute to developing new technologies, achieve objectives and improve the competitiveness of aviation biofuels.

A fact that deserves to be highlighted and verified during the research is that the airline industry lacks an interest in developing an alternative fuel that meets the sector. This lack can be supplied with di-amyl ether biofuel, as already proved in this study. However, the biggest obstacle is not exclusive to biofuel production but the favorable political measures and a regulatory framework for the production and use of biofuels in aviation. In this study, it was possible to demonstrate the potential of the AHP method and Fuzzy logic as a tool for assessing competitiveness in the production of biofuels. In addition, the result will contribute scientifically to expanding the knowledge base, making it possible to be a reference in future studies in research on the competitiveness and development of biofuels. The joint and simultaneous use in evaluating the competitiveness of aviation biofuel, using the AHP method and Fuzzy logic, can be used as a starting point in future works.

As a limitation of this study, one can cite the potential of specialists to provide the necessary information for constructing the hierarchy and priorities in the AHP method and formulating rules based on Fuzzy logic. In addition, it may be questioned whether the assessed competitiveness criteria encompass the entire study. Thus, as a recommendation in future studies, a group of interested parties can be formed to support the specialist who will define the priorities in the AHP method and the rule base on the Fuzzy logic, which generates more excellent reliability in the evaluation system. Another recommendation is the application in other aviation biofuels using this study in a complementary way to analyze the results.

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