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Assessing the current scenario of the Brazilian biojet market

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ABSTRACT

This study reviews the current scenario and the main uncertainties associated with the Brazilian biojet market. It also provides recommendations to mitigate the identified uncertainties. This study will enable the supply chain, research institutions, and policymakers to organize for better strategic action, identify research fields, and the need for R&D investment. As a global contribution, this assessment will share the Brazilian experience with other countries, thereby helping them to build a solid foundation for a new biofuels industry. Based on the evaluation, it is concluded that there are many technological and commercial uncertainties, such as lack of technical dominance in producing alternative feedstocks with higher energy density, lack of laboratory infrastructure for biojet certification, logistical issues, high cost of feedstocks and refining routes, and lack of public-private investment. On the other hand, organizational and social uncertainties are reduced. The following recommendations are made to reduce the uncertainties: greater operational planning between stakeholders and the government, integration with national and international agencies, and improving Brazil's regulations. It is also suggested that the best regional feedstocks, productive routes, and locations for establishing productive facilities should be analyzed based on technical evaluation such as multicriteria analysis. Besides, the study suggests incentives and investments in storage and mixing facilities, and in laboratories that already have infrastructure for certifying aviation fuels.

1. Introduction

Air transport accounts for approximately 2% of global greenhouse gas (GHG) emissions [1], and exponential growth in the sector can increase this share significantly [2–5]. Revenue passenger kilometers (RPKs) increased by 66.8% in ten years (2005–2015), up 7.4% only from 2014 to 2015 [1]. This growth increased the consumption of fossil jet fuel and, thereby, GHG emissions [6–8].

In 2009, the International Civil Aviation Organization (ICAO) adopted the target of achieving carbon neutral growth from 2020 onward and reducing net emissions by 50% by 2050 (compared to the 2005 levels) [9]. In addition, the ICAO approved the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) [10], which compensates for any annual increase in international aviation carbon emissions above the 2020 levels.

In Brazil, the growth of jet fuel consumption also raises concerns. Therefore, national commitment to reduce GHG emissions was assumed through the Nationally Determined Contribution (NDC) during the 21st Conference on Climate Change (COP 21). Brazil pledged to reduce its emissions by 37% by 2030 and 43% by 2030 (compared to 2005) [11]. A transition in the use of fossil fuels by renewable energy sources is needed to honor the NDC. In this sense, the use of biojet produced from renewable feedstocks can contribute to achieving these ambitious goals [6,12–16] as these fuels have the potential to reduce emissions by up to 80% during their life cycle [1].

Brazil has already progressed in the use of renewable sources in its energy matrix [17–19]. Renewable sources in the Brazilian energy matrix comprise 42%, which is much higher than 13% of the world average and 9% in the Organization for Economic Cooperation and Development (OECD) countries [19]. Nonetheless, the use of biofuels in aviation is still negligible because they are considered to have low competitiveness with fossil jet fuels [2,13,16,20].

Some renewable energy sources are considered non-competitive with fossil energy fuels [21,22]. However, competitiveness must be observed from the social and environmental dimension and not only from the economic aspect [21,22]. The use of biojet fuels have many potential benefits, such as reducing GHG emissions, generating employment and income, reducing regional disparities, and encouraging research and innovation. Moreover, this new market can create opportunities for the diversification of the energy matrix, for the reduction

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of dependence on fossil jet fuel, and for the development of the national biojet industry. However, certain uncertainties need to be addressed to build a solid foundation for the biojet market in the country.

Studies have also investigated the major challenges of the biojet market in the world. This shows that the difficulties faced by emerging markets are not unique to Brazil. Connelly et al. [23] identified the most impacting actions in the global biojet industry from multicriteria analysis. Moraes et al. [24] pointed out the main challenges for sustainable production of biojet from sugar, starch, oil, lignocelluloses, and wastes. The evaluation was based after conducting workshops with the concerned stakeholders. Hari et al. [25] evaluated the main routes, opportunities, and challenges of the global biojet market based on literature reviews. Gegg et al. [2] studied the key drivers and constraints of the global biojet market based on interviews with stakeholders in Europe and North America. Smith et al. [16] evaluated the main drivers and barriers to the adoption and diffusion of biojet in the US Pacific Northwest region from stakeholder interviews. Kamali et al. [26] evaluated the social and governance issues for biojet supply chains using literature reviews and expert surveys. In the Brazilian context, Cortez et al. [13] identified the main technological, economic, and sustainability barriers of the Brazilian biojet market by holding stakeholder workshops.

To address these challenges, several biojet-related studies have been conducted worldwide. These studies seek to mitigate the challenges associated with feedstocks and routes. Kubátová et al. [27] proposed a new path in the thermal cracking of canola and soybean oils for biojet production. Mupondwa et al. [28] evaluated the techno-economic feasibility of commercial production of biojet from the hydrotreatment of camelina oil. Han and Wang [29] evaluated GHG emissions from ethanol-to-jet and sugar-to-jet, two biofuels produced from a biological route. Gómez-De la Cruz et al. [30] evaluated the economic and environmental dimensions of biojet production from microalgae oil. Tzanetis et al. [31] evaluated the impact of hydrothermal liquefaction reaction conditions on biojet production costs and the performance of GHG emissions. Ganguly et al. [32] made a life cycle assessment of biojet production from residual woody biomass. In Brazil, Klein et al. [33] made a comparative techno-economic evaluation and environmental feasibility study of biojet production from different routes integrated into the Brazilian sugarcane biorefineries. Silva et al. [34] made a technical evaluation of biojet production from the catalytic deoxygenation of macauba oils. Bailis and Baka [35] evaluated GHG emissions and any direct land use changes resulting from the production of biojet from jatropha. De Sousa et al. [36] studied biojet production from hydroprocessing of palm kernel oil.

To guide new studies and strategic investments in the Brazilian biojet market, it is necessary to identify the main uncertainties in the sector, the current market regulatory scenario, and the action plans implemented by stakeholders and the Brazilian government to mitigate these uncertainties. Identifying the current regulatory environment and developing initiatives helps to understand how policymakers and stakeholders are concerned with mitigating the challenges. This also enables to suggest improvements to the current regulatory acts in order to contribute to the biojet market. The identification of actions under progress clarifies how Brazil is attempting to overcome these barriers.

This study elucidates the current biojet regulation scenario in Brazil, identifies the actions taken by the Brazilian government and stakeholders to promote the biojet market in the country, and presents and discusses the technological, commercial, organizational, and social uncertainties associated with this market using the TCOS framework [37–39]. The TCOS framework is an analytical tool based on Technology Futures Analysis (TFA), and is presented in Section 2 (Theoretical Framework). Since the emerging biojet market falls within the definition of innovation [40], the TCOS framework is used as a guideline to evaluate the uncertainties present in this market.

The proposed assessment complements the study by Cortez et al. [13]. The authors [13] evaluated the main techno-economic and sustainability barriers in the Brazilian biojet market, but did not discuss the key initiatives that are underway to promote the production and use of biojet in Brazil. In addition, the authors did not present the current Brazilian regulatory scenario and the organizational aspects of the biojet production technology, which involves the assurance of intellectual protection.

Therefore, evaluating these important aspects will provide a better understanding of the current Brazilian biojet market. This study also proposes strategic recommendations to help advance a sustainable aviation biojet industry in the country. The study will enable supply chains, research institutions, and policymakers to organize for strategic action, identify fields of research, and the need for R&D investments. Besides, this assessment shares the Brazilian experience with other countries, thereby helping them build a solid foundation for a new biofuels industry.

2. Theoretical framework

The market is increasingly competitive and globalized, demanding quality and efficiency of products, services, and processes [41]. As a result, technological innovation has become central to economic development and to government policy [41]. Besides, innovation must be applicable, viable, and should be acceptable to both market and society [42,43]. In this context, Technology Future Analysis (TFA) comprises methodological tools that seek to analyze innovation and its future impact from different perspectives [44]. Therefore, TFA can be applied to assess the uncertainties involved in innovation and the results can be used to support strategic decision making [45].

The TFA methods are grouped into nine families [46–48]:

(1) Creativity Methods - These methods link innovation to creativity [49]. Thus, these methods assume that new products need to have perspicacity to become competitive in an increasingly demanding market. Two methods stand out: brainstorming and Theory of Inventive Problem Solving (TRIZ) [48].
(2) Expert Opinion Focus Groups - This family of methods is based on professionals' experience in relation to a certain subject [50]. By using these tools, it is possible to explore the most interesting futures and key impediments to achieving them, based on experience [48]. It fits into the panels and iterative survey method.
(3) Trend Analysis – These methods are based on the hypothesis that the patterns of the past are maintained in the future. Trend analysis uses techniques to extrapolate the time series into the future [49]. The differential of these methods is the ability to discard inconsistent scenarios from a logical trend assessment [46]. Long wave analysis and precursor analysis are the techniques used in this method.
(4) Monitoring and Intelligence Methods - These methods are based on acquiring information about individual choices [46]. That is, they are data acquisition tools, correlating with the prospective methods [46]. These methods seek to evaluate and interpret a compilation of information, such as scientific research and patents. From this evaluation, monitoring and intelligence methods can be associated with benchmarking in order to propose changes to future planning [48]. Demographics stand out in this family of methods.
(5) Statistical Methods - These methods analyze objective data [46]. They refer to models that seek to identify and measure the effect of one or more independent variables on the future behavior of a dependent variable. Correlation analysis and bibliometrics stands out in this family of methods.
(6) Scenarios - These methods are widely used in contemporary approaches to assist in the assessment of uncertainties involved in business environments [49]. The Field Anomaly Relaxation Method (FAR) is an important method in scenario assessment [48].
(7) Modeling and Simulation - These methods enable the understanding of phenomena from the creation of an artificial medium

that tries to imitate a real environment [49]. Modeling and simulation allow prediction of techno-economic changes. Similar to the methods of other families, these tools assist in the evaluation of systems, allow the proposition of solutions and procedures, and facilitate decision making [48]. Cross-Impact Analysis and Diffusion Modeling are the techniques of this family.

(8) Descriptive and Matrices Methods - This family of methods uses expert experience, data series, modeling understanding, and information technologies to improve future understanding [49]. Risk analysis and roadmapping are important tools of this group.

(9) Valuing/Decision/Economics Methods - A technical evaluation allows decision making to be more efficient. Hence, the methods of this family reduce the uncertainties associated with the process and help decision makers to act strategically [46]. Different approaches, such as the Analytic Hierarchy Process (AHP) process and Decision Tree Analysis, have been adapted and used.

Combined methods are interesting to compose different perspectives for better prediction [49]. Phillips et al. [48] indicate that the best responses of the TFA analysis derive from an aggregation of methods. The TCOS framework [37–39] merges the characteristics of "Trend Analysis", "Monitoring and Intelligence Methods", "Scenarios", and "Valuing/Decision/Economics Methods" to evaluate the uncertainties involved in an innovation. This method is based on evaluating the uncertainties of the current scenario, thereby allowing to propose strategic recommendations for the market and policymakers to guarantee the future success of the innovation.

The TCOS framework serves as a guide for assessing the perceived uncertainties involved in innovation. It answers the questions proposed by Hall et al. [37–39]:

(1) Technological uncertainties - Is there technological feasibility? Does the technology involved in the innovation process achieve results comparable to existing technologies?
(2) Commercial uncertainties - Is there commercial viability? The new product has a competitive price compared to the replaced product?
(3) Organizational uncertainties – Is a protection mechanism of the technology involved in this innovation?
(4) Social uncertainties - Is there socio-political legitimacy? How would this innovation affect society?

For Hall et al. [37–39], this debate is fundamental for assessing the barriers that must be overcome to ensure the success of an innovation. The process of overcoming the uncertainties of innovation is called legitimacy [37,40,51] and it has two dimensions: cognitive and socio-political [37,40,51]. Cognitive legitimacy is developed through technical knowledge and industry analysis [51], covering three types of uncertainties: technological, commercial, and organizational [37,40]. Socio-political legitimacy, on the other hand, is developed by understanding the value society places on an invention [37,40,51], and encompassing social uncertainty [37,40]. According to the authors [37,40,51], an innovation has legitimacy when cognitive and socio-political legitimacy coexist. This assessment assumes that a new invention must be strategic to secure profits and to guarantee socio-political legitimacy, and technological viability alone does not assure success of an innovation [37,40,51].

Based on the TCOS framework, Silvestre [48] evaluated how Brazil has emerged as a leader in the oil market without neglecting environmental concerns. Melander and Tell [52] evaluated the uncertainties involved in the development of an energy storage unit. Hall et al. [39] evaluated how the uncertainties in Brazil's agriculture have shaped the biofuel chain in the country. Hall et al. [53] discussed the challenges faced by the base-of-the-pyramid (BoP) consumers, who are impoverished socio-economic groups from the underdeveloped regions with low economic participation.

3. Methodological procedures

The study methodology is based on three steps: 1. Review of regulatory acts, 2. Review of literature, and 3. TCOS framework. Review of regulatory acts presents an overview of the current legislations to regulate biojet in Brazil. The literature review aims to identify the actions implemented by the Brazilian government and stakeholders to promote the biojet market, and to identify the uncertainties present in this emerging market. Finally, the TCOS framework [37–39] is applied to guide the discussion on the main uncertainties identified.

3.1. Review of regulatory acts

In this step, a review of Brazil's regulations for the biojet market is presented. The search is conducted through the electronic system of legislations available on the Brazilian National Agency of Oil, Natural Gas, and Biofuels (ANP) website [54]. All the legislations that regulate the activities of the Brazilian oil, natural gas, and biofuels industries (including biojet) are available on the electronic system.

The electronic system provides all the regulations elaborated by the ANP since 1998 and organized as resolutions, technical and administrative orders, normative instructions, authorizations, and dispatches. The collection also presents the Federal Constitution, laws, decrees, and provisional measures approved by the National Congress. Moreover, the ANP consolidates regulatory acts from various ministries and federal agencies whose activities directly relate to the oil, natural gas, and biofuels industry.

The keywords were in the Portuguese language because it is a Brazilian regulatory system. The search was performed using keywords such as "*bioquerosene*" and "*querosene de aviação alternativo,*" which translate into English as "biojet." The review process consisted of identifying regulatory acts that contain important definitions and rules regarding the production, consumption, distribution, and quality of the biojet.

3.2. Literature review

The initiatives under development in Brazil were identified based on searching for studies published in peer-reviewed journals in the last fifteen years (from January 2003 to January 2018), and on the website of ICAO [55], which provides a tool to select, by country, the main initiatives for the development of biojet in aviation. Moreover, regulatory acts that directly target the incentive to produce and use biojet, identified in the previous section, were also considered. The search for scientific studies was performed using the tool provided by the Brazilian Federal Agency for Coordination of Improvement of Higher Level Personnel (CAPES) [56], which considers Scopus and Web of Science (WOS) databases, among others. To make the review more efficient, advanced search using the "AND" and "OR" conjunctions was considered. The term "biojet," which is used in the current study, is not a consensual term used in literature. Different studies used various terms, such as "biokerosene," "renewable aviation fuel," "alternative aviation fuel," among others. Besides, the terms "initiative" and "action" can be used to describe actions structured by stakeholders and the government to develop the biojet market. Thus, the keywords considered include biojet OR "aviation biofuel" OR "renewable jet fuel" OR "aviation renewable fuel" OR "renewable aviation fuel" OR "biokerosene" OR "alternative aviation fuel," AND Brazil* AND initiative* OR action*. The asterisk (*) was used in "Brazil,*" "initiative," and "action" because it enables to search for all variations of the term. Thus, the terms "Brazil," "Brazilian," and "Brazilians" were considered. Likewise, the same reasoning applies to "initiative" and "action." From the search results, it is seen that four scientific studies cited actions consolidated by stakeholders or the government to promote the biojet market.

The uncertainties involved in this market were identified based on searching for studies published in peer-reviewed journals during the last fifteen years (from January 2003 to January 2018). CAPES [56] also performed the search. The following keywords were considered: biojet OR "aviation biofuel" OR "renewable jet fuel" OR "aviation renewable fuel" OR "renewable aviation fuel" OR "biokerosene" OR "alternative aviation fuel" AND Brazil* AND challenges OR barrier OR uncertain*. The search resulted in 93 scientific articles published in peer-reviewed journals. Of the 93 studies, 21 were selected because they presented at least one barrier faced by the Brazilian biojet market. Studies that presented international barriers or terms referring to uncertainty in a different context of the biojet market were not selected. The identified uncertainties were allocated into four groups: technological, commercial, organizational, and social, according to the TCOS framework [37–39].

For analyzing organizational uncertainties, patents that were deposited in Brazil and globally over the last fifteen years (from January 2003 to January 2018) were surveyed. In Brazil, the deposited patents were collected from the database of the National Institute of Industrial Property (INPI) [57] and 6 patents were found. Global patents were collected from the database of the United States Patent and Trademark Office (USPTO) [58], and 137 patents were found. The following keywords were used: biojet OR "aviation biofuel" OR "renewable jet fuel" OR "aviation renewable fuel" OR "renewable aviation fuel" OR "biokerosene" OR"alternative aviation fuel" OR "alternative jet fuel" OR "alternative kerosene."

3.3. TCOS framework

The TCOS framework [37,38] was used to assess the main uncertainties in the Brazilian biojet market. Considering biojet as an innovation, Silvestre defines innovation [40, pp. 173] as, "*the introduction of a new good, a new method of production, a new organizational form, the opening of a new market, and the use of a new source of supply of raw material or semi-finished products*." In this study, the TCOS framework was used to answer the questions proposed by Hall et al. [37–39], cited in Section 2. Based on the TCOS framework, it was possible to guide the discussion on the main uncertainties of the Brazilian biojet market and to evaluate its legitimacy. Moreover, based on this evaluation, recommendations were proposed to promote the biojet market.

4. Results and discussion

The results regarding review of the regulatory acts are presented in Section 4.1. The results for the initiatives under development to promote the Brazilian biojet market are presented in Section 4.2. Finally, the main uncertainties related to the Brazilian biojet market, identified in the literature review, are discussed from the perspective of the TCOS framework in Section 4.3. In addition, recommendations for remedying the uncertainties are proposed.

4.1. The Brazilian biojet regulation

Table 1 presents the main regulatory acts related to the biojet market in Brazil, identified in the ANP legislation system. Most of the regulations are from the ANP itself since it is responsible for regulating and supervising all economic activities related to the production, import, export, transfer, transportation, storage, marketing, distribution, and quality of fuels, including biojet [59]. Such attribution is provided in the Brazilian Law No. 9478 promulgated in 1997 [59], which established a new regulatory agency.

In Brazil, biojet is part of a fuel group defined as alternative aviation kerosene, according to ANP Resolution No. 63 of 2014 [64]:

- Alternative aviation kerosene is a fuel derived from alternative sources, such as biomass, coal, and natural gas, destined for consumption in aircraft turbines, and produced by processes that comply with the ANP Resolution No. 63 of 2014 [64].

The alternative aviation kerosene is derived from a wide variety of sources such as coal, gas, vegetable oil, and animal fats [7]. Notwithstanding, the Brazilian Law No. 12,490 of 2011 (Biofuels Law) [62] considers only biomass derivatives as aviation biofuels. This is because the sustainability of aviation fuels directly relates to the feedstock used [15,66], and an alternative aviation kerosene will not necessarily be more sustainable than conventional fossil jet fuel. This consideration, due to the Brazilian regulations, is an important step toward recognizing that not all alternative aviation fuels are biojet. However, the use of renewable feedstocks does not guarantee that the aviation fuel produced is sustainable. Thus, it is necessary to consider that feedstocks produced without observing important social [36,67,68], environmental [24,69], and economic [70,71] criteria do not produce sustainable aviation fuels.

In Brazil, approval for new alternative aviation kerosene is obtained from ASTM International, formally known as American Society for Testing and Materials. This institute published a qualification and certification guide to simplify the approval process of new alternatives such as aviation kerosene for use in aviation. The specific standard is ASTM D4054 [72].

Any alternative aviation kerosene, including biojet, must comply with the performance standards of the conventional jet fuel. In this way, biojet fuels must have the properties that characterize them as "drop-in," that is, they must be completely interchangeable or blend with fossil jet fuel so that adaptation of current aircraft engines is not necessary [12]. Furthermore, the biojet should be safe for engines of expensive airplanes, and alternative fuels [73] should not damage aircraft engines.

Currently, ASTM [74] and Brazil [64] have approved and certified five alternative aviation kerosene fuels: Fischer-Tropsch Synthetic Paraffinic Kerosene (FT-SPK), Fischer-Tropsch Synthetic Kerosene with Aromatics (FT-SKA), Hydroprocessed Esters and Fatty Acids (HEFA), Synthetic Iso-paraffin from Fermented Hydroprocessed Sugar (SIP), and

Table 1
Key regulatory acts related to the Brazilian biojet market.

Regulatory acts	Description	Reference
Brazilian Law No. 9478 of 1997	It provides for a national energy policy and activities related to the oil industry. Besides, it establishes the National Council of Energy Policy (CNPE) and the ANP	[59]
ANP Resolution No. 17 of 2006	It regulates the distribution of aviation fuels in Brazil	[60]
ANP Resolution No. 37 of 2009	It establishes the specifications for the fossil jet fuel to be used either pure or blended with biojet fuels	[61]
Brazilian Law No. 12,490 of 2011	It includes biofuels in the Brazilian Law No. 9478 of 1997, and other provisions regarding the oil industry.	[62]
Brazilian Bill No. 506 of 2013	It provides for the creation of the National Biojet Program. The program aims to encourage research and achieve sustainability of the Brazilian aviation fuels.	[63]
ANP Resolution No. 63 of 2014	It establishes the specifications for biojet and its blend with fossil jet fuel	[64]
Brazilian Law No. 13,576 of 2017	It creates the National Biofuels Policy (RenovaBio) that aims to stimulate the production and use of biofuels in the country, based on sustainability, competitiveness, and safety.	[65]

Alcohol to Jet SPK (ATJ-SPK).

The five types of fuels approved represent three technological routes: 1. the thermochemical route, represented by the FT-SPK and FT-SKA, 2. the chemical route, represented by HEFA, and 3. the biochemical route represented by SIP and ATJ-SPK. The FT-SPK, FT-SKA, and HEFA can be blended at up to 50% in volume with petroleum-derived jet fuel to obtain a drop-in fuel [74]. On the other hand, SIP and ATJ can be blended at up to 30% [74]. The FT-SKA and ATJ-SPK were approved by the end of 2016, and ANP is in the process of including these new alternative aviation kerosene in the Brazilian regulation.

The ANP Resolution No. 63 of 2014 [64] presents the specification table for each alternative to aviation kerosene, and ANP Resolution No. 37 of 2009 [61] presents the specifications for fossil jet fuel (JET-A1).

The ANP Resolution No. 63 of 2014 [64] defines the blend composed of alternative aviation kerosene and fossil jet fuel as BX Aviation Kerosene (JET-BX):

- BX Aviation Kerosene (JET-BX): This is a blend composed of a single type of alternative aviation kerosene, as specified by the ANP, following ASTM, mixed with fossil jet fuel (JET-A1), in which X represents the percentage by volume of alternative aviation kerosene in the mixture [64].

After mixing, BX Aviation Kerosene should meet all the parameters required for JET-A1, as well as complementary parameters: aromatics, distillation for 10%, 50%, and 90% recovered volume, lubricity, and viscosity at $-40\,^{\circ}C$ [64].

Even with the quality traceability control, after mixing, it is not possible to verify the presence of the alternative aviation fuel in the mixture with JET-A1. This is because the two components have equivalent chemical composition and there are no standardized methods for this differentiation. Thus, after blending, the product that goes to airports continues to be treated as JET-A1.

In terms of supply, the ANP Resolution No. 17 of 2006 [60], regulates the distribution of aviation fuels. In the Brazilian model, the producer (oil refinery) markets the product with the distributor of aviation fuels. The distributor, in turn, trades the product with the reseller until it reaches the final consumer, the airline industry. It is also worth noting that the fossil jet fuel or alternative aviation kerosene, including biojet, can be purchased via imports. However, due to the difficulty in distinguishing the biojet from fossil jet fuel, ANP prohibits the import of JET-BX [64].

Finally, the two regulatory acts identified in the results of this review (Table 1), Brazilian Bill No. 506 of 2013 [63] and Brazilian Law No. 13,576 of 2017 [65] are not detailed in this section. These regulations deal mainly with regulatory measures to promote the biojet industry in Brazil. For this reason, they are presented in the next section (Section 4.2).

4.2. Brazil's action plan for promoting biojet

Based on the search results of studies published in peer-reviewed journals, four scientific studies [13,17,25,75] cited the creation of the Brazilian Alliance for Biojet (ABRABA, *Aliança Brasileira para Biocombustíveis de Aviação*). Other actions consolidated by stakeholders or the government were not identified in the search for scientific studies. The Brazilian initiatives cited by ICAO are Brazilian Alliance for Biojet (ABRABA) and Brazilian Biojet Platform (BBP). The latter also has regional operations, namely Minas Gerais, Pernambuco, and Rio Grande do Sul platforms. Finally, the following regulatory acts presented in Table 1: Brazilian Law No. 13,576 of 2017 [53], and Brazilian Bill No. 506 of 2003 [63] are considered because they are regulations that seek to encourage the production and use of biojet in Brazil. The actions are detailed as follows:

4.2.1. Brazilian Alliance for Biojet (ABRABA)

In 2010, airlines and biojet research initiatives, biomass producers, and aeronautical manufacturers established the Brazilian Alliance for Biojet (ABRABA) [13,17,25,75,76]. The objective of this alliance is to promote security of supply, and the eventual competitiveness of the biojet against the fossil jet fuel [64]. The alliance hopes to position Brazil as a leader in this technology, just as it is a leader in terrestrial biofuel production.

ABRABA focuses on promoting public and private initiatives that seek the development, certification, and commercial production of sustainable biojet. The goal is also to obtain biofuels with equivalent levels of quality, safety of use, cost, and adequate production capacity, in relation to fossil jet fuel [76].

According to ABRABA, Brazil's engagement in biojet development projects will empower farmers, technicians, and industries to create a consistent technology base. ABRABA cites the benefits of establishing a policy for the future of aviation [76]: 1. promote technological development of universities, regulatory agencies, and private organizations, 2. engage the agricultural sector and research institutions in the search for high productivity genetic material and suitable agroenergy crops, 3. add value to the biomass produced in the country, 4. assess the impact of using sustainable biofuels in aviation, and 5. ensure security and energy independence for defense aviation.

4.2.2. The Brazilian biojet platform

In 2012, the Brazilian Biodiesel and Biojet (UBRARIO) launched the Brazilian Biojet Platform (PBB) [77]. The platform was supported by Boeing, Petrobras Distribuidora (BR Aviation), AirBP (jet fuel distribution unit), BID (Inter-American Development Bank), and Curcas (a company specializing in the expansion of sustainable energy projects). The proposal is to discuss the creation of a policy to encourage the use of biojet, affirming the socioeconomic and environmental importance of using biofuels insertion not only in terrestrial transport but also in air transportation [55,76].

The proposal also aims to form an integrated chain of value “from field to wing” and to fill all identified gaps within the sector. The platform provides for the regional use of feedstocks and seeks to integrate family agriculture with agribusiness. In this way, the best feedstock for biojet production guarantees maximum regional development. Another important point is the continued investment in research, development, innovation in productive processes, and logistics for biofuel distribution [55,76]. Based on Brazil's biodiversity, availability of territory, climate and labor, the Brazilian Biojet Platform addresses the use of various supply chains of feedstocks, such as sugarcane, jatropha, camelina, used cooking oil, macauba, algae, babassu, tallow, and several other regional feedstocks [55,76].

4.2.3. Minas Gerais, Pernambuco, and Rio Grande do Sul biojet platforms

In 2014, the Minas Gerais Government launched the Minas Gerais Biojet Platform in partnership with research institutions, universities, producers of sustainable feedstocks, technology suppliers, stakeholders in logistics and industry processes, and airlines, among others. The Minas Gerais Biojet Platform is integrated with the Brazilian Biojet Platform, collaborating with the aim of producing low carbon fuels and reducing GHG emissions from the aviation sector, while promoting sustainable regional development [78]. The main axes of the Minas Gerais Biojet Platform are logistics, infrastructure, certification, and R&D focused on feedstocks with bioenergy potential such as macauba, supported by Law No. 19,485 of 2011 [78].

The Brazilian Ministry of Agrarian Development (MDA) chose macauba as feedstock as the plant has high potential for family farming in the Brazilian state of Minas Gerais. The macauba plant is still in the research and development phase, and the Federal University of Viçosa (UFV) has actively engaged in researching this species during the past ten years, with sponsorship from Petrobras [79].

The first workshop on alignment of the Minas Gerais Biojet Platform was held in April 2015. The Platform's Action Plan was submitted for public consultation in May 2015. In June of the same year, the document was published in the Official State Gazette, which completed the legal formalities for its institution. Since August 2015, UBRABIO has made efforts to implement the demonstration technical units (UTDs) in several municipalities across the state and introduce macauba as a native species for the recovery of Permanent Preservation Areas (PPAs), legal reserves, and degraded pastures. The platform works in partnership with MDA, and the State Secretariat of Agriculture, Livestock and Supply of Minas Gerais for providing training in family agriculture in the macauba consortium with annual crop alternatives. The purpose of the UTDs is to demonstrate the technical and economic viability of macauba for biojet production [79]. The project seeks to plant one million hectares of macauba in Minas Gerais, aiming to recover PPAs, legal reserves, and degraded pastures by 2030 [79].

In 2015, two platforms were created in the same mold of the Minas Gerais Biojet Platform: Pernambuco Biojet Platform and Rio Grande do Sul Biojet Platform. The two platforms are focusing on the development of research that will make new feedstocks feasible for producing cleaner aviation fuels. The Rio Grande do Sul Biojet Platform is based on the use of soybean and soybean meal, while the Pernambuco Biojet Platform is based on sugarcane and family production of other feedstocks used in the biojet refining process, such as castor bean and macauba [80]. Although macauba is already under evaluation, consistent with the scope of the Minas Gerais Biojet Platform, the Pernambuco Biojet Platform is also studying the plant because it is a feedstock with potential agricultural production in both the Brazilian regions.

4.2.4. National program for the production and use of biojet (Brazilian Bill No. 506 of 2013)

In 2013, former senator Eduardo Braga proposed Bill No. 506 of 2013 [63] for launching the National Program of Biojet, as already established for biodiesel. The program aims to encourage research and production of energy from biomass that does not compete with food production, in order to develop a sustainable aviation biojet for Brazil [63].

The bill recognizes that the following measures should be adopted to encourage research, production, marketing, and use of biojet: 1. increase credit to the biojet market from CIDE tax (Contribution of Intervention in the Economic Domain), which is an important and complex tax levied on some specific products in Brazil; 2. allocate financial resources from agencies and development banks for biojet projects; and 3. establish fiscal incentives for research, development, production, marketing, and use of biojet by the federal government [63]. The main benefits expected from this policy for the biojet market are similar to those from ABRABA.

However, this proposed Bill is yet to be approved and is being processed in the Brazilian Senate. The Committee on Environment, Consumer Protection, Supervision, and Control (CMA) has already approved the Bill. The Commission for Constitution, Justice, and Citizenship (CCJ) is currently evaluating the Bill.

4.2.5. National biofuels policy – RenovaBio (Law No. 13,576 of 2017)

The Brazilian government created the National Biofuels Policy (RenovaBio) in December 2016 in order to stimulate the production of biofuels in Brazil. Nearly a year after the launch of RenovaBio, Law No. 13,576 of 2017 was adopted to regulate the policy [65]. RenovaBio is already a part of the country's energy policy and its practical effects will begin in December 2019 [81]. The main objective of the policy is to expand the production of biofuels in Brazil, taking into account predictability, sustainability (environmental, economic, and social), as well as market growth [82]. Beyond that, RenovaBio could also contribute to achieving the commitment to reduce GHG emissions announced by Brazil through the National Determined Contributions (NDC) [82].

To achieve the proposed objectives, the government has set the national emission reduction targets for the distribution fuel matrix, defined over a 10-year period. The goal defined by the Ministry of Mines and Energy (MME), a priori, is to reduce GHG emissions by 10.1% for the fuel matrix by 2028 [81]. The proposal is part of the target to increase production and consumption of biofuels in Brazil. National targets will be divided into annual individual targets for fuel distributors, which will take into account each other's market share. Another instrument will be the certification systems for biofuels production. The certification process will be carried out through inspector firms accredited by the ANP [81]. According to the certification, a note on energy-environmental efficiency will be attributed to each producer. This note will reflect the individual contribution of the producer agent to mitigate a specific quantity of GHG emissions in relation to its fossil substitute [81]. The connection between distributors' targets and the certification of biofuels production will be accomplished with the creation of CBIO (Biocarbon Descarbonation Credit), a tradeable financial asset issued by the biofuel producer. Fuel distributors, in turn, will meet the target by demonstrating ownership of CBIOs in their portfolio [82].

This initiative, despite covering all the biofuels produced in the country, is has greatest potential (practical effect) for the development of the biojet market in Brazil. Beginning 2019, commercialization of biofuels that effectively reduce the carbon footprint will be encouraged in the country, opening up a range of investment opportunities for the biojet.

4.2.6. Summary of Brazil's actions to promote the biojet market

The evaluated actions seek, in general, to promote the sustainable development of the biojet market. The environmental concern is linked, above all, to the achievement of the established international goals, as well as the goals ratified by Brazil to reduce GHG emissions. All the actions presented contribute their own value for the development of the aviation industry. The initiatives formed by stakeholders, such as ABRABA, BBF, and regional platforms, are fundamental to improving the interaction between the different links of the productive chain. This interaction is beneficial for the joint development of new routes and new feedstocks for biojet production. In addition, these initiatives increase the visibility of the Brazilian biojet market vis-a-vis important global institutions such as the ICAO. Similarly, government initiatives are of paramount importance in the development of this market. This is because the results of the government's actions appear more quickly, from the imposition of regulations that focus on stimulating the sustainability of the sector in the long term. The Brazilian Bill No. 506 2013 [63] will produce immediate effects on the Brazilian biojet industry once it is approved, as it will provide financial incentives to the market. Likewise, Law No. 13,576 of December 26, 2017 [65], which has already been approved, will come into effect in 2019 and will likely produce immediate results with the encouragement to promote commercialization of biofuels that reduce GHG emissions. Table 2 summarizes the actions evaluated.

4.3. Evaluation of the Brazilian biojet uncertainties and recommendations

The results of the literature review (identification of uncertainties present in the Brazilian biojet market) are presented in Table 3.

Next, the TCOS framework will conduct the discussion about identified uncertainties. In addition, during the discussion, recommendations will be made about the main uncertainties.

4.3.1. Technological uncertainties

Technological uncertainties refer to technical and scientific barriers to innovation [38]. That is, the technical difficulties to achieve the feasibility and viability of the innovation are addressed in this section.

Although BX Aviation Kerosene is compatible with fossil jet fuel, several technological uncertainties exist in this market. Trial testing and operating commercial flights with biofuels have eliminated doubts

Table 2
Consolidated Brazilian initiatives to promote the biojet market.

Actions	Founder	General Goals
Brazilian Alliance for Biojet (ABRABA)	Airlines and research companies, biomass producers, and aeronautical manufacturers	Promote security of supply and competitiveness of the biojet with fossil jet fuel
Brazilian Biojet Platform (BBP)	Brazilian Union of Biodiesel and Biojet (UBRABIO)	Discuss a policy to encourage the use of biojet, showing the socioeconomic and environmental importance of introducing biofuels in aviation
Regional Biojet Platform	Minas Gerais, Pernambuco, and Rio Grande do Sul Government	Contribute to biojet production in Brazil based on logistics, infrastructure, certification, and research on feedstocks with bioenergetic potential
Brazilian Bill No. 506 of 2013	Brazilian Government, Former Senator Eduardo Braga	Create the National Biojet Program to stimulate research and encourage the production of biojet through financial incentives. The focus is to produce energy based on biomass that does not compete with food production
RenovaBio	Brazilian Government	Promote the expansion of biofuels with a focus on predictability and sustainability (environmental, economic, and social)

about the compatibility of the products. The main technological uncertainties relate to the technological immaturity of the biojet production routes, characterized by low production of this biofuel in the country. Beyond that, there are uncertainties related to the scale and yield of the alternative energy crops and technological uncertainties that can be observed from a logistic perspective. The lack of laboratory infrastructure necessary for the certification of these fuels compromises the distribution of the product. Although production of SIP in Brazil on a pilot scale is underway, certification is done from abroad. Thus, it is necessary to implement the required infrastructure and technical training for certification in Brazil. The barriers to laboratory infrastructure also impact the current structure of airports. Since laboratories that conduct full certification of BX Aviation Kerosene are not available, airports now need to use dedicated systems for this product. The reason being that although BX Aviation Kerosene is drop-in, ASTM D7566 [74] requires that the blending of this fuel with fossil jet should be certified again after the mixing process. Thus, airlines choose to handle and transport BX Aviation Kerosene through dedicated systems so that they do not have to recertify the blend as required by ASTM D7566 [74]. Furthermore, it should be noted that the current infrastructure at Brazilian airports does not support storage, handling, and transportation of both types of fuel in dedicated systems. Therefore, the use of BX Aviation Kerosene in Brazil has always occurred in small volumes and in specific cases, such as the 2014 FIFA World Cup and sporadic flights.

Of all the conventional routes for biojet production, the HEFA process currently has the potential for large-scale production. Thus, this process is considered more consolidated around the world. [7]. Neuling and Kaltschmitt [7] state that all routes for biojet production are more complex than the HEFA process. This is because the HEFA is the key biofuel route that uses the biosynthesized oil produced by the plant itself as input. The other routes initially involve destruction of the biosynthesized molecules for subsequent synthesis of the interest product [7].

Thus, leveraging the lower technological complexity involved in the HEFA process, it is suggested that more investment should be made for the development of this route. Thus, it will be possible to take advantage of the country's strong agricultural potential that extends to the production of oilseeds. Besides, this process is already consolidated in Brazil, being similar to mineral diesel hydrotreatment, a process practiced in Brazilian refineries to remove nitrogen, aromatics, and sulfur present in mineral diesel. Later, more in-depth studies on other technologies such as the SIP production technology in Brazil are suggested. Studies for producing biojet from municipal solid waste and household effluents such as sewage for solving daily waste disposal problems are also recommended [23,96].

Uncertainties related to the scale and yield of energy crops have a technological and commercial approach. The technical domain still lags in achieving the potential increase in scale and yield of some feedstocks. The scale of production and yield of these feedstocks impact biojet cost. In this section, only the technological aspects will be addressed. The commercial approach to feedstocks will be discussed in the next section (Section 4.3.2).

To reduce the technological uncertainties related to feedstocks, it is necessary to increase the productivity scale and yield of potential feedstocks for energy purposes. In Brazil, soybean and sugarcane are considered as potential feedstocks for the production of biodiesel and ethanol, respectively [97]. Soyabean is considered as the feedstock with short-term potential for the production of biojet HEFA [12]. This is because soyabean has long dominated the production technology and Brazil is a global reference for technologies that produce soyabean in tropical and subtropical areas. The large number of registered cultivars proves the technological dominance.[1] The Ministry of Agriculture, Livestock and Supply (MAPA) provides a platform called the National Register of Cultivars (RNC) [98], which indicates the number of cultivars registered for each plant species. A study conducted on May 20,

Table 3
Key uncertainties in the Brazilian biojet market.

Type of Uncertainty	Uncertainties	Reference
Technological	Reduced technical dominance of feedstocks with higher energy density, such as macauba palm and jatropha	[4,12,13,17,24,83–89]
	Most refining technologies are still under development	[4,12,13,17,84,87,90]
	Product yields are still considered low for large-scale production	[13,84]
	Few studies are available on the use of second-generation feedstocks in bio-refining scenarios	[13,24,83,85]
Commercial	High cost of feedstocks, refining routes, and final product	[12,13,17,24,83,84,91–94]
	Lack of public-private investment	[13,84]
	Lack of an effective regulatory framework that confers commercial predictability on the market	[13,91]
	No clear destination for co-products that could help the financial performance of the biojet market	[13,84]
	Infrastructure issues	[13,17,24]
Organizational	Lack of effective coordination between different stakeholders	[13]
Social	Lack of consensus on the use of well-established methodologies to evaluate emissions compromising environmental gain assessment	[13,17,24,26,85,91,95]
	Lack of well-defined sustainability criteria for the biojet industry	[13,24,26,91]
	Food security risks	[13,24,26,83,88,94]

2017 on the RNC platform [98] showed 1674 cultivars registered for soybean cultivation (*Glycine max* L. *Merr.*). This number is very high, considering that for other crops such as jatropha and macauba, only one cultivar is registered for each species.

Nonetheless, since soy is the main feedstock for biodiesel production in Brazil, it is not strategic to rely on just one feedstock for the two biofuels because the two markets could compete with each other [99]. In this sense, it is important to develop other crops that have higher energy density to meet the criteria related to diversification and regionalization to reduce the technological complexity of producing alternative feedstocks.

To reduce the uncertainties cited, several initiatives were developed to compute value to the renewable feedstocks produced in the country, based on the engagement of the agricultural sector and research institutions [76]. Thus, it is necessary to develop genetic material with high productivity and suitable agro-energy crops. Moreover, the Brazilian initiatives, especially in the context of the Minas Gerais Biojet Platform, are working to identify and evaluate existing refining technologies in the country to promote the implementation of pilot biorefineries [78]. Thus, it will be possible to create conditions for partnerships between companies in Minas Gerais, and domestic and foreign companies.

Regarding laboratory infrastructure, the need for establishing reference centers for biojet certification is being evaluated. Important laboratories being equipped with the facility include Center for Research and Technological Analysis (CPT) of the ANP and Fuel Testing Laboratory (LEC) of the UFMG [78].

4.3.2. Commercial uncertainties

Commercial uncertainties are the barriers hampering the economic viability of an innovation, that is, they relate to costs [38].

The biggest commercial uncertainty in the Brazilian market is the cost of biojet, which is not yet competitive with fossil jet fuel. The final cost of a biojet depends on the feedstock price, refining technology, and logistics costs [12]. Among these, feedstock cost is the main factor contributing to the final product cost, which represents more than 70% of the final cost [12]. Evaluating the cost of soybean oil in Brazil for biojet production, for example the cost of crude oil for producing fossil jet fuel, it is possible to understand why the price of the biojet is not yet competitive with the fossil fuel. The average price of soybean oil in Brazil in 2016[2] was US$ 847.9 per metric ton. On the other hand, the price of oil reached US$ 47.24 per barrel. Converting this value to a ton of oil, the cost would be US$ 347.3,[3] which is approximately 2.4 times lower than the cost of soybean oil. According to Velázquez et al., [8] the final cost for the biojet fuel is about 2–2.5 times higher than the cost of fossil jet fuel.

To reduce the production costs of this biofuel, it is essential to increase the scale of production [2,16,17,23,75]. However, to increase the scale of production it is necessary to eliminate the uncertainties associated with the production cost of feedstocks, refining technology, and logistics costs. For this, it is necessary to evaluate the regional feedstocks on multiple criteria to choose those with the greatest energy potential for biojet production. It is also necessary to promote the mapping of strategic locations to implant refining centers, considering the shorter transportation distances of the feedstock suppliers and the bigger consumers, namely airports. In this context, Multiple Criteria Decision Analysis (MCDA) is a valuable tool in the decision-making process of prioritizing one alternative over others [100,101].

Although biojet is a drop-in fuel, investments are needed for building storage and mixing facilities. Consumption of aviation fuel is mostly concentrated in the Southeast region of Brazil. However, abundant and cheap agricultural land is available in the interior of the country, far from the centers of consumption. Thereby, improving logistics is necessary for economic competitiveness between the various pathways for biojet production [16]. To solve these logistical problems, it is necessary to develop detailed studies for promoting investment in infrastructure for railways and waterways to develop feedstocks with higher potential for biojet production and the best location for installing refining centers.

As regards the costs involved in refining, the first investment suggestion in the HEFA process is reiterated. De Jong et al. [102] evaluated the short-term economic viability of the biojet production routes and concluded that the HEFA process is the best short-term option because the technology is commercially well developed worldwide. Besides, this is a low-cost technology. Furthermore, to reduce production costs and to increase competitiveness with fossil fuels, it is necessary to analyze the methods for the main pathways identified and implement pilot plants for alternative fuels with maximum potential. However, this requires investment from both the government and the private sector [23].

Initially, an alternative to avoiding the situation where consumers pay more for the biojet is to provide financial incentives for per unit of fuel produced. Thus, incentives can support the development of this new market and new economy. Moreover, it is necessary to adapt the existing lines of credit and finance to the particularities of this new industry, including future carbon prices in the amortization of rates. Another important mechanism to mitigate the commercial uncertainties is the adoption of differentiated taxation for the biojet productive chain. Differentiation of the tax burden on renewable fuels increases competitiveness against fossil fuels.

To encourage investments in biojet production, the Brazilian government is focusing on regulating the National Program of Production and Use of Biojet, through Bill No. 506 of 2013 [63], in the same mold as the National Program of Production and Use of Biodiesel (PNPB) [103]. Even though the current global environment of low oil prices indicates that it is impracticable to produce fuels from renewable feedstock, incentives can guarantee competitiveness. If the Bill is approved, the economic viability of biojet fuels can be achieved, as in the case of the biodiesel market in Brazil. The analysis of the price behavior of diesel and biodiesel fuels indicates that biodiesel price has remained higher than the price of fossil diesel since the launch of the PNPB in 2004 [104]. However, this trend reversed in 2013, initially with the convergence of prices, and later biodiesel prices were lower than diesel [104]. This comparison shows that government support is fundamental for consolidating the productive chain to achieve future competitiveness for biojet fuels.

4.3.3. Organizational uncertainties

Organizational uncertainties are based on the appropriation of technology and its profits [38]. Without a mechanism that guarantees intellectual property protection, the inventor will not appropriate the advantages as the profits of the innovation, even if it has economic and technically viability [38,105].

Patents are important tools to guarantee intellectual protection and serve as a tool to stimulate innovation, with propagation and sharing in a safe way for the inventor. Hence, it is possible for the inventor to redeem his/her financial application and still benefit from the profits derived from the commitment [106]

The organizational uncertainties of this new market are considered reduced because the innovation is patentable in any technological route used to produce the biojet. Large chemical companies such as Solazyme

[1] Cultivars are plant species that have been improved with the introduction of a feature they did not previously possess. This new characteristic differentiates the new cultivar from the other varieties of the same species. The new cultivars developed in Brazil are registered with MAPA and form a part of the National Genetic Patrimony [98].

[2] From 11/27/2015–11/27/2016 [119].

[3] The calculation was based on: 1. cost of Oil Brent on November 27, 2016 (barrel of oil to $ 47.24) [120], 2. barrel conversion ton based on the average (Arab Light) 33.5°API (1 barrel of oil = 0.136 t) [121], and 3. dollar exchange rate on November 27, 2016 ($1 = R$3.42) [122].

Inc., Neste Oil Oyj, Exxon Mobil Research and Engineering Company, UOP LLC, Gevo Inc., Syntroleum Corporation, BP Corporation North America Inc., among others, have filed patents with the United States Patent and Trademark Office (UPSTO). Of these patents, most refer to the three technological routes used in this process: thermochemical, chemical, and biochemical. It is reiterated that these three routes represent the five alternative aviation kerosene approved by the ANP and the ASTM. Of the 137 international patents granted, 37 are related to the Fischer-Tropsch reaction, that is, the thermochemical route; 60 are related to the hydrotreating chemical route of fatty acids, and 34 are related to the biochemical route, which involves fermentation.

In Brazil, only six patents were deposited, according to a search on the National Institute of Industrial Property (INPI). Of these, public universities deposited five patents while Petroleo Brasileiro S.A. (PETROBRAS) filed only one patent. These patents present the process of trans-esterification of oils and fatty acids, followed by purification. This route, the same as biodiesel production (used in diesel engines), is not part of the list of conventional routes to alternative aviation kerosene [25,107,108]. The use of biodiesel as aviation fuel does not show much efficiency [25,108]. According to Liu et al. [107], biodiesel was also considered an alternative to jet fuel because it could be used as a substitute for mineral diesel. However, its poor cold-flow properties and higher oxygen content limit its commercial application as a jet fuel [107]. Furthermore, the biodegradability of biodiesel may cause biological growth during storage and affect stability [109]. Biodiesel has a very high freezing point compared to petroleum-based aviation fuel, and this makes it insufficient for high altitude flights [25]. The presence of polyunsaturated and unsaturated fatty acids decreases the stability of biodiesel fuels due to the oxidation of the unsaturated sites [25]. To some extent, the presence of ester groups makes biodiesel polar and this leads to the formation of emulsion and, therefore, separation of water becomes difficult [25,109]. Insufficient supply of feedstock for both biofuels and the private economy are other problems associated with biodiesel [110].

More importantly, a great window of opportunity exists, as there are no patents deposited in Brazil from conventional routes. Brazil already has some experience in three conventional routes. The Brazilian oil refineries use the hydrotreatment process. It should also be noted that a large territorial extension, considerable frontier for agricultural expansion, and optimal climatic conditions, guarantee higher potential for the cultivation of several oilseeds in Brazil [111]. Oil from these seeds can be used for producing biojet from the HEFA process. Regarding the biochemical route, Brazil has experience generated by the Amyris large-scale demonstration plant. The production of SIP from the fermentation of sugarcane by genetically modified microorganisms represents a business opportunity for this market in Brazil. Regarding the thermochemical route, although there are still no commercial scale plants in Brazil, this technology has already been tested for application in the near future by Petrobras in partnership with the British Compact GTL [112]. The project has two biomass gasification units and one Fischer-Tropsch unit in a demonstration plant installed in the test park in Aracaju, the capital of the State of Sergipe, Brazil [113]. The process uses cane bagasse and aims to produce high purity biofuels such as biojet, diesel, and renewable lubricants [113].

Organizational uncertainties are reducing because the actors involved in the Brazilian biojet market are not offering resistance to this new product. On the contrary, agents of the productive chain, universities, research institutions, airlines, and the government are all working towards the same goal: to promote the biojet market in Brazil. However, while institutions are working towards this goal, there is no effective coordination between these important players [96]. The joint action of different players makes the development of this market strategic, achieving better results within a short period.

4.3.4. Social uncertainties

Social uncertainties are associated with how innovation affects those who are not part of the market directly, such as civil society [38]. When a paradigm shift occurs through technological innovation, society tends to change. Furthermore, social uncertainties are linked to the social acceptance of the changes brought about by innovation, which includes transformation in the environment. For this reason, environmental challenges are framed in the social uncertainties associated with innovation.

There are a few social uncertainties in this market. This makes the social legitimacy of the biojet market high. There is a strong social appeal for the insertion of renewable fuels in the national energy matrix. Moreover, the possibility of increased employment generation, income, and regional development further increases the social legitimacy of this market.

The sustainability theme from the environmental perspective is prevalent in not only Brazil but also globally [114]. The annual climate change conferences (COPs) are already in their 23rd edition and have set deadlines and targets for developed countries to reduce their respective GHG emissions [115]. Innovation benefits the environment and is indispensable for society as it reduces the negative externalities of pollution [116]. In the case of biojet, it can contribute to the achievement of the targets set out in the Paris Agreement. Nonetheless, it is important to evaluate new biofuels that actually mitigate GHG emissions. Aviation fuels can be derived from a wide variety of sources such as coal, gas, vegetable oil, and animal fats. However, only biomass derivatives are considered biojet in Brazil [59]. This is because the sustainability of aviation fuels directly relates to the feedstock used in the production, and it is not necessary that an alternative jet fuel will be more sustainable than the fossil jet fuel.

To corroborate that not all alternative aviation fuels reduce GHG emissions, Stratton et al. [117] presented a comparative life cycle analysis (LCA) among FT's with and without Carbon Capture and Sequestration (CCS) technology, fossil jet fuel, and HEFA produced from oils, such as salicornia, switchgrass, palm, soybean, jatropha, rapeseed, and seaweed. The study showed that FT emissions without CCS technology are 123% higher than the fossil jet fuel baseline, while FT with CCS increases emissions 11–15% relative to the baseline. In turn, HEFA or FT from biomass gasification presents GHG emissions substantially lower than FT from fossil feedstock and conventional fossil jet fuel, showing promise of reduction of the carbon footprint.

The consolidation of biodiesel and ethanol in the energy matrix in Brazil shows that although there are geopolitical interests involved, environmental concern has become paramount for the partial migration of a country historically linked to the fossil fuel sector. However, it is suggested that the introduction of any fuel into the Brazilian energy matrix, including renewables, should be preceded by life cycle analysis (LCA) and by economic and social criteria in order to have a real notion of sustainability.

Even though the social uncertainties related to this market are small, it is important to note that the implementation of social sustainability criteria is critical to the production of biojet fuels [26]. In the Brazilian context of great opportunities to increase the productivity of existing farmland, there is a need to accelerate the production of biojet without jeopardizing food security or neglecting the farmer's workforce. It is necessary to establish legal mechanisms to ensure incentives for biojet only when it is demonstrated that the production of such fuels complies fully with national laws and regulations, especially environmental and social guidelines, protection of natural forests, land use zoning, and protection of farm workers [79].

Just as the learning curve is important for production cost analysis, there is a need to improve social and environmental performance to build a sustainable biojet industry. Since aviation is largely an international business, it is important to use sustainability criteria that are internationally acceptable, such as the Roundtable on Sustainable Biofuels and Bonsucro. To address the social and environmental gaps, Brazilian institutions need to take advantage of the opportunity to produce energy feedstocks to promote a sustainability culture in Brazil's agriculture, overall [13]. Research initiatives are critical to improving the performance of sustainability indicators through the development of appropriate tools.

4.3.5. Summary of uncertainties, and comparison with other studies

The Brazilian biojet market continues to face many technological and commercial uncertainties. These difficulties mainly relate to the technical domain and the costs involved in the production of feedstocks and refining routes. Organizational uncertainties are considered reduced because inventors who contribute to this market can appropriate their inventions through patents. Besides, stakeholders and the government are working to develop the sector, as can be seen in the partnerships and actions presented in Section 4.2. Social uncertainties are also low because society supports the use of biofuels in the energy matrix. Moreover, the use of biofuel contributes to the reduction of GHG emissions, directly benefiting society.

The discussion presented in this paper is consistent with the main results obtained by Hari et al. [25], who evaluated the main opportunities and challenges of the global biojet market. The authors identified the following global challenges: 1. high cost of feedstocks, routes, and final fuel, 2. availability of feedstocks with higher energy potential to meet the sustainability criteria, 3. environmental impact due to the use of pesticides and fertilizers that compromise soil and water quality, 4. social impact arising from the concern of food scarcity, and 5. compatibility with conventional fuels. The concern regarding environmental impact cited by [25] correlates directly with the uncertainty "lack of real estimates related to the environmental gain for biojet generated by feedstocks and routes" (identified in Table 3 of the present study). However, the challenge of biojet with conventional fuel compatibility can be correlated with the uncertainty "reduce technological maturity of refining routes." This is because the ASTM approves only a few routes for biojet production. Nonetheless, other routes need to prove their compatibility with conventional fuels.

The findings of the present study are also in agreement with the study by Gegg et al. [2], who evaluated the main challenges of the biojet market from the perspective of the European and North American stakeholders. According to the authors [2], the main challenges are: 1. high cost of production, 2. lack of investment, 3. lack of sustainable feedstock supply, 4. inadequate legislation, 5. restricted environmental control for biofuels, and 6. lack of supply chain certification and logistical constraints. One of the challenges identified by the authors [2] that deserves special mention, in comparison with the findings of the present study, is the logistical issue. Brazil has continental dimensions, challenging the logistics of supplying feedstocks and distribution of fuels. Beyond that, it presents infrastructure problems at airports due to the difficulty in handling BX Aviation Kerosene in systems dedicated to this product. If the European and North American experts pointed out this challenge, it is inferred that the problem of certification infrastructure is not exclusive to developing countries such as Brazil. Smith et al. [16] also pointed out the logistics question of the biojet as a major challenge in the US Pacific Northwest.

The challenge related to feedstocks, one of the findings of this study, is also in agreement with the findings of Connelly et al. [23]. The authors ranked the most important actions stakeholders and the government should take. Among the 37 actions, "investing in research to reach more productive feedstock" was ranked the most important. Fiorese et al. [118] also concluded that R&D is critical to the development of feedstocks for the production of advanced biofuels.

In the case of Brazil, the uncertainties identified in the present study are in agreement with the findings of Cortez et al. [13], who show that the scientific studies are consistent with the stakeholders' perception. This is because the uncertainties identified in the present study are based on a review of the existing literature, and the uncertainties identified by Cortez et al. [13] were based on stakeholders' perceptions. The main challenges pointed out include: 1. limited information about species with high potential for bioenergy, 2. high costs, 3. lack of information about process feasibility, 4. problems of infrastructure, and 5. problems of sustainability. However, in relation to Brazil, Moraes et al. [24] stated that the greatest challenge to sustainable biojet production is compliance with the sustainability criteria. This assertion was made after evaluating the sustainability of biojet production from sugar, starch, oil, lignocelluloses, and wastes. The authors [24] concluded that there are several requirements of sustainability but, in many cases, the knowledge required to apply the requirements is lacking.

5. Final remarks and practical implications

The low social uncertainties indicate that this emerging Brazilian market has socio-political legitimacy. However, this new market does not yet possess cognitive legitimacy, which involves technological, commercial, and organizational uncertainties. Achieving legitimacy for the Brazilian biojet market depends on joint stakeholder and government actions. The Brazilian government is committed to the issue, as indicated by the main regulatory actions of the biojet market (Table 1). The specifications of the biojet, fossil jet fuel, and their mixtures are consistent with international specifications, which show Brazil's commitment to comply with the international quality of this product. Besides, the creation of the National Biofuels Policy (RenovaBio), which will take effect in 2019, shows Brazil's first steps toward promoting biofuels that effectively reduce GHG emissions. It is expected that the implementation of this policy will generate immediate effects, given the incentive to commercialize biojet as a substitute for the fossil jet fuel. Another key regulatory act for this market is Bill No. 506 of 2013 [63], and the National Congress is yet to approve it. The approval of this regulation will create a legal basis for financial incentives for research, production, and use of biojet in the country. The initiatives formed by stakeholders are also contributing to the promotion of the Brazilian biojet market with the joint development of new routes and feedstocks for regional biojet production. Thus, the regulatory acts (presented in Section 4.1) and the initiatives (presented in Section 4.2) contribute in some way to mitigating the uncertainties of the biojet market (presented in Section 4.3).

The present study is limited to identifying the current scenario of the Brazilian biojet market, focusing on the uncertainties and initiatives to promote the sector. A comparison between the actions taken in Brazil and the other countries was not presented, as it is being considered a limitation of the present study. This comparison was not made because it requires in-depth research on the actions taken in other countries and involves not only a review of the literature but also a thorough search of the regulatory acts of each country. Thus, this comparison is suggested for future work.

Finally, the findings of this study propose the following general recommendations that policymakers and the Brazilian government can apply, and can be studied in future scientific works:

(1) In order for the Brazilian initiatives to deliver better results, strategic operational planning must be developed with the joint participation of various stakeholders and the government. The planning should be presented to ICAO and discussed with international organizations.
(2) Social criteria (e.g., food security, income effects, worker conditions, among others) and economic criteria (e.g., productivity, total energy balance, GDP increase) should be included in the RenovaBio and implemented by Law No. 13,576 of 2017 [65]. Sustainability involves the social, economic, and environmental pillars. However, the current policy considers only environmental criteria related to the reduction of GHG emissions.
(3) Immediate investments should be made in storage and mixing facilities and in laboratories that already have infrastructure for certifying aviation fuels, such as the LEC (fuel laboratory of the Federal University of Minas Gerais) and the CPT (ANP research

laboratory). Brazil must have the technical capacity to perform all the biojet specification standards in order to optimize product distribution.

(4) Existing credit and financing lines must be adapted to the particularities of this new industry, including future carbon costs in the amortization of rates. The adoption of differentiated taxation on the biojet production chain is recommended. Differentiation of the tax burden on renewable fuel increases the competitiveness of the biojet versus fossil jet fuel.

(5) To apply financial resources more efficiently, investment in agriculture should be based on technical evaluation. A satisfactory technical evaluation is the identification of the most promising feedstocks in each region of the country using multicriteria analysis tools. These tools are very useful in decision making involving the prioritization of one alternative over others [100,101]. It is suggested that multicriteria evaluation is performed to select a strategic location for producing the promising feedstocks.

(6) To apply financial resources more efficiently, technical evaluation should be the criteria for investing in processing routes. The multicriteria analysis can be used to define the best productive routes and locations for establishing the productive units. Moreover, techno-financial viability criteria should be considered.

(7) Since studies [7,102] indicate that HEFA is the best short-term option for biojet production, for future work a techno-economic evaluation of the feasibility of HEFA in Brazil is suggested. Thus, Brazil can benefit from its strong potential to produce oilseed and its hydrotreatment experience in oil refineries.

6. Conclusion

Brazil has emerged as a leader in the production and use of biojet fuels, in view of its experience with biofuels as well as the potential for producing renewable feedstocks. Broadly, this new market is an example of environmental economics. Therefore, it is essential to overcome the main technological, commercial, organizational, and social uncertainties involved in this market.

The main technological uncertainties relate to the scale and yield of energy crops. Brazil is already in contact with the main production routes of biojet fuels, but large-scale production is yet to mature technically and this is attributable to the negligible biojet production in the country. Besides, Brazil does not have laboratory infrastructure necessary for certifying these fuels. The main commercial uncertainty in this new market is that the cost of biojet is not yet competitive with fossil jet fuel. The final cost of a biojet is influenced by the feedstock prices, refining technology, and logistics costs. Among these, the cost of feedstock is the main factor for the composition of the final cost of the product, which can represent more than 70% of the final price [12]. The cost of the renewable feedstock for biojet production is still much higher than the cost of oil for producing the fossil jet fuel.

From an organizational perspective, there are few uncertainties, considering that biojet developers can take advantage of the benefits of innovation through patents. All the technologies involved in biojet production are patented. Moreover, the actors involved in the Brazilian biojet market do not offer any resistance to this new product. In contrast, agents in the productive chain, universities, research institutions, airlines, and government are all working toward the common goal of promoting the biojet market in Brazil. However, while institutions are working toward this goal, coordination between these important players is not effective. The joint action of different players makes the development of this market strategic, achieving better results within a short period. From a social perspective, there are small uncertainties because social support for the production and use of biofuels is strong. Civil society supports the use of biofuels in Brazil's energy matrix because the aim is to reduce the country's carbon footprint and develop a national biojet industry, besides increasing jobs and income.

Different regulatory acts and actions created by stakeholders and policymakers are consistent to mitigate the key uncertainties. Commitment to the challenges of the Brazilian biojet market will create a favorable scenario to strengthen investments to increase the supply of potential feedstocks and expand the industrial capacity of biojet production.

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