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Article

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Research on Biodiesel in the National Institute of Science and Technology for Energy and Environment: An Analysis through Scientometry, and Complex and Social Networks

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ABSTRACT

The National Institute of Science and Technology for Energy and Environment (INCT E and A) is a virtual network of scientific-institutional cooperation focused on research for energy sustainable use and environment preservation. This article aimed to identify production and articulations of researchers affiliated to INCT E and A in biodiesel research in the period from 2009 to 2020, based on scientometric, and social and complex network analysis. Altogether 76 articles involving biodiesel theme were analysed and a network of 212 authors from 48 institutions with a high level of collaboration was identified. Network topological properties were calculated, making it possible to find central researchers and affirm that it presents the small world phenomenon. It was also possible to observe that scientific production by the researchers occurred especially between the years 2009 and 2014. After this period, biodiesel theme stopped attracting INCT E and A researcher's attention, demobilizing a network at a moment when Brazil chose biofuels as a decarbonizing strategy for transport matrix through the National Biofuels Policy (RenovaBio).

Keywords: Biodiesel, Bibliometrics, Scientometrics, Social Network Analysis
JEL Classifications: Q2, Q4, Q5, C6, C8

1. INTRODUCTION

Biodiesel is a biofuel derived from the processing of biological sources and with properties similar to diesel, which stands out for being biodegradable, non-toxic and essentially free of sulfur and aromatic compounds (Knothe, Gerpen & Krahl, 2018; Ramos et al., 2017; Monteiro et al., 2008; Rezende et al., 2021).

Biodiesel can be used pure or mixed with diesel in different proportions. Currently, it is being used in at least 49 countries in the form of mixtures that vary between 5% and 20 and its production is concentrated in 11 countries that account for 80% of global production, highlighting: Indonesia (17%), United States United States (14.4%), Brazil (13.7%), Germany (7.4%), France (5.0%) and the Netherlands (4.6%) (REN21, 2022).

In Brazil, biodiesel has become the main biofuel used in the decarbonization of road transport, which consumed more than 90% of the diesel used in the country in 2021 (EPE, 2022a) and will be responsible for 224 MtCO2e of the 484 MtCO2e from energy consumption projected for 2030 (MME, 2021).

As there is no prospect of using advanced biofuels (e.g. Hydrotreated Vegetable Oil or HVO) on a large scale in the country (EPE, 2022b), Brazil should continue to bet on increasing the addition of biodiesel to diesel in different proportions, which can reach B25 (70% diesel and 25% biodiesel) in 2030, but a series of additional efforts are still required from the actors involved in the Brazilian's biodiesel production chain. (ANFAVEA; BCG, 2021).

The efforts to promote biodiesel in Brazil began with the launching of the National Biofuels Program (PROBIODIESEL) in 2002, and materialized by the Program for Biodiesel Production and Use (PNPB) launched in 2005 (Ramos et al., 2017). Through the implementation of a new legal framework, the PNPB introduced biodiesel into the Brazilian energy matrix, by making mandatory the blending of biodiesel with diesel (Silva et al., 2014).

PNPB success is attributed to several factors, including land availability, soil and climate conditions for biodiesel production, as well as a consolidated legal framework, and technological domain (Ribeiro and Silva, 2020; Silva et al., 2014).

In order to promote the scientific and technological development of biodiesel, the Ministry of Science, Technology and Innovation has launched the Brazilian Biodiesel Technology Network (RBTB). RBTB involves universities, research institutions, government agencies and private companies in order to identify and eliminate technical, socio-environmental and economic barriers throughout the whole biodiesel chain. It has become an example of a national scientific-technological base structured to support and guide the PNPB program (Menezes, 2016; Suarez and Meneghetti, 2007).

Another federal government initiative, which also benefited biodiesel research, was the National Institutes of Science and Technology Program (INCT). It is a set of virtual, multicentric and multidisciplinary research and development institutes (Bosio et al., 2019). INCT is a typical model of science, technology and innovation system (ST and I) in a more advanced consolidation stage in Brazil (Macedo, 2015).

Created in 2008, the INCT Program is characterized by a transversal and priority action of the Science, Technology and Innovation Action Plan (STIAP). INCT was planned and implemented to occupy a strategic position in the National Science and Technology System (NSTS), developing consistent and priority research programs for the national scientific and technological development (CGEE, 2019).

To this end, the best research groups in cutting edge areas of science or strategic themes for Brazilian sustainable development were mobilized with three well-defined missions: (i) to conduct scientific research; (ii) to invest in human resource training and; (iii) to transfer knowledge to society. A fourth mission was assigned to institutes focused on ST and I applications: knowledge transfer to the business sector or to the government (Andrade and Lopes, 2012; Ministério Da Ciência, Tecnologia, 2008; MCTIC, 2016).

Most of the INCT institutes has been founded in 2009, and until 2014, in order to conduct research on topics directly related to strategic areas of the ST and I Action Plan, 125 institutes were created comprising the following areas: engineering and information technology, agricultural, exact, natural, human, social, nanotechnology, health, ecology, environment, and energy sciences (MCTIC, 2016). In 2020, Brazil has 104 institutes working in the aforementioned areas (CNPq, 2021).

Among the institutes related to the energy area and biofuels, the INCT for Energy and Environment (INCT E and A) is one of the most active. Its head office is located at the Federal University of Bahia (UFBA) and is housed at the Interdisciplinary Center for Energy and Environment (CIEnAm), located in Salvador, Bahia, Brazil (Andrade and Lopes, 2012).

INCT E and A started its activities in 2009 with 59 researchers from 39 research groups from 12 institutions: UFBA, UFRJ, USP, UEL, UFPR, UFSC, UFRGS, SENAI CIMATEC, UESC, UNEB, UEFS, and UESB (De Andrade and Guarieiro, 2011; P. Vieira et al., 2016). In 2020, there were 87 researchers from 26 institutions are registered, 18 of which are national and 8 are foreign (INCT EA, 2020). INCT E and A maintains a close interaction with the industrial sector, involving a significant number of small and large companies, such as Petrobras S/A, Braskem, and Repsol Ypf, and Aerosol Dynamics, as well as incubators such as E and A Energia e Ambiente, and Solar Engenharia Sustentável (INCT EA, 2020).

The research at INCT E and A is focused on optimization and eco-efficient use of energy, comprising the preparation, characterization, testing, and evaluation of produced biofuels, associated with by-products valorization; formulation and certification of blends of fossil fuels and biofuels; combustion in engines and dynamometers; emissions impact evaluation in Brazilian urban centers, and studies of other matrices of environmental interest (INCT EA, 2020).

In order to conduct biodiesel research, the scientists can count on 37 laboratory facilities affiliated to the institute (INCT EA, 2020), and an optimized pilot plant installed at UFBA, for biodiesel production from residual oils and fats and/or *in natura* oils. This plant has a production capacity of 5 million liters per year, contributing to several studies on technological routes, preparation, and testing of biodiesel blends (Torres, 2008), resulting in a wide range of publications in national and international journals.

In this context, this article aimed to identify the production and articulations of researchers affiliated to INCT E and A in biodiesel research field from 2009 to 2020, based on scientometric analysis and social and complex networks.

Network studies originated from mathematical investigations carried out by Euler, resulting in graph theory (Newman et al., 2006), which was applied in sociology by Jacob Levy Moreno, introducing the idea of representing social structures in sociograms in an attempt to capture collective behavior complexity (Scott, 2011). Since then, network analysis has become a powerful tool that can be used in a strategic planning of research programs, as it allows tracking, visualizing and understanding interrelationships formed between participants in a collective through co-authorship established in scientific publications, in addition to identifying and pointing out trends for research development (Knoke and Yang, 2008; Morel et al., 2009).

Considering that the research team from INCT E and A institute have published a large number of articles addressing biodiesel, this scientific production could be identified and its metadata used in a scientometric evaluation. Further, along with a co-authorship network it was possible to enlighten the current state and trends of research with biodiesel in the INCT E and A.

2. METHODOLOGY

This research is exploratory and descriptive in nature, as it provides information on a topic, describing it without the researcher's interference. It is a quantitative study in character, as it involves the processing of quantitative data from scientometric research, which is the technical procedure adopted for data collection (Freitas, 2013).

Scientometrics or scientometric research aims to analyze scientific and technological activity through mathematical and statistical techniques applied to productions, scientific policies and technological applications. It also includes bibliometrics, which favors access and analysis of research carried out by different actors, such as countries, universities, research centers and groups, scientific journals and researchers, enabling the creation of various indicators, such as production, visibility, human resources training, funding, co-authorship standards, among others (Osabe and Jibu, 2018; da Silva and Bianchi, 2001; Vanti, 2002).

Such indicators can be used at different analysis levels. In this research, scientometric analysis of generated indicators was restricted to micro aggregation level, that is, it was limited to a specific theme developed by INCT E and A researchers.

The research followed the workflow for bibliometric research suggested by Zupic and Čater (2015) consisting of five steps: (i) to define research question and to choose appropriate methods to answer it; (ii) to select databases; (iii) to choose appropriate software; (iv) to decide visualization method to present the results; and (v) to interpret the results obtained. Steps i and ii have already been described in previous sections.

2.1. Data Collection

Scientific knowledge is no exception to the data boom, and it is a consensus among researchers that scientific production has increased exponentially in recent years (Cantu-Ortiz, 2018), requiring a good strategy for data recovery for scientometric analysis. Therefore, data mining becomes useful in dealing with this task, as it enables extraction of useful and non-trivial knowledge from different databases.

Database collection and assembly took place in multidisciplinary bibliographic databases: Web of Science (WoS) by Clarivate Analytics, Scopus by Elsevier and in the INCT E and A repository (http://inct.cnpq.br/web/inct -e-a), an institutional hotsite provided by CNPq. Thus, it was possible to provide a scientometric description of research on biodiesel by the institute, and to understand its evolution from 2009 to 2020.

The search strategy used for article retrieval was a specific strings creation for the Core Collection of WoS and Scopus, since a single string does not work in all databases (Kitchenham and Brereton, 2013). Orthographic variations and Institute acronyms were used, and the following terms were selected: "INCT Energia and Ambiente," "INCT Energia e Ambiente," "INCT EA," "INCT E and A," "Natl Inst Sci and Technol Energy and Environmet." As for the INCT E and A hotsite, the search term used was "Biodiesel." Chart 1 presents the information retrieval strategy in the three aforementioned databases.

The search was restricted to articles, reviews and proceedings papers or conference papers, as long as they were presented at a conference and later published in a journal. No language restrictions were imposed. File, interview, editorial, theses and dissertations, book chapters, abstracts, meeting abstracts and patents were excluded, which makes this criterion a limitation of the adopted search strategy, since they are also documents resulting from collaboration.

2.2. Data Organization and Analysis

First of all, the analysis begins with data pre-processing, which is one of the most important steps for creating and analyzing scientific networks, as data collected in bibliographic databases usually contain errors (Cobo et al., 2011).

Based on this premise, articles' data were exported to Microsoft Excel, where they underwent a first pre-processing stage. This step was essential, as the dataset analyzed came from three different databases and their metadata needed to be standardized and organized in a single spreadsheet.

At the end of this step, a.csv file (comma-separated-values) was generated and a new error search was performed enabled by the

Chart 1: Information retrieval strategy in the selected databases

Database	String/search term	Selected documents	Period
WoS (Core Collection)	ALL=("inct energia and ambiente" OR "inct energia e ambiente" OR "inct energia ambiente" OR "natl inst sci and technol energy and environm" OR "inct ea" OR "inct e and a")	Articles Review articles	2009-2020
Scopus	AFFIL ("inct energia and ambiente" OR "inct energia e ambiente" OR "inct energia ambiente" OR "natl inst sci and technol energy and environm" OR "inct ea" OR "inct e and a")		
Hotsite INCT E and A	Biodiesel		

Source: Prepared by the authors. INCT E and A: Institute of science and technology for energy and environment, WoS: Web of science

Open Refine data cleaning application (https://openrefine.org), resulting in a file new version for creating collaborative networks using the free software VOSviewer (www.vosviewer.com).

VOSViewer was specifically developed to build, visualize and explore scientific networks from bibliometric data. These networks can be co-authored (by countries, organizations and authors), co-occurring (of keywords and terms), citation, Co-citation and bibliographic coupling (Van Eck and Waltman, 2010).

The software uses the VOS positioning technique (similarities visualization) to generate two-dimensional networks, where network nodes are positioned in such a way that the distance between any pair of nodes reflects their similarity degree (association strength). Hence, strongly related nodes are located close to each other, whereas less strongly related nodes are located further away from each other (Van Eck and Waltman, 2010).

VOSViewer also has an advanced layout technique that allows communities detection, which even can be improved through available parameters, allowing data reduction to select relevant information and accepting thesaurus. This can be used to merge different spellings of an author, organization, country or term name (Van Eck and Waltman, 2014; Waltman et al., 2010), helping to overcome one of the most difficult challenges for an analyst: disambiguation of names (Cantu-Ortiz, 2018).

In this research, thesaurus (.txt file) were created for researchers and organizations names in order to avoid double counting and normalize spellings used before the networks were generated. To disambiguate the authors' names, information from the Lattes Curriculum (http://lattes.cnpq.br) and the Open Researcher and Collaborator ID - ORCID (https://orcid.org/) was used.

The files generated by VOSViewer were also exported to Gephi (https://gephi.org) and Pajek (http://mrvar.fdv.uni-lj.si/pajek) software for additional topology calculations and behavior analysis of identified collaborative networks.

3. RESULTS AND DISCUSSION

This section is divided into two parts. The first one focuses on scientometric performance indicators, in which results obtained from databases prospection, publication evolution, dissemination channels applied, knowledge areas and fundings are discussed. In the second part, collaborative patterns between institutions and researchers are presented and analyzed, based on analysis of collaboration networks.

3.1. Analysis of Scientometric Indicators

In an advanced search in the WoS Core Collection, the ALL field label was chosen, because it finds articles with all terms listed in other field labels. Thus, 347 articles that mentioned the INCT E and A in the C1 field (author affiliation) were retrieved, indicating that at least one author had his affiliation linked to the Institute. After analyzing the titles, keywords, and abstracts, 42 articles were selected. This step was repeated in Scopus, but the AFFIL label was used, as it searches for terms in fields referring to authors' affiliation. Thus, 54 articles that mentioned the INCT E and A were retrieved, and 13 articles aligned with the theme of this research were selected. Finally, 41 articles were retrieved using the term "biodiesel" on the INCT E and A hotsite (http://inct.cnpq.br/web/inct-e-a/artigos-publicados/).

The articles obtained were cross-referenced to identify overlaps and eliminate duplications. This cross-examination was carried out through a comparison of the fields of title, journal name, year of publication, and DOI, leaving at the end 76 articles to compose the research corpus (Figure 1).

It is noteworthy that 24 (72.73%) of the 33 articles exclusively found on the INCT E and A website are also indexed in WoS. However, the authors did not mention the institute in the C1 field, which made it impossible to retrieve these articles by the search string used, revealing a standardization problem of affiliation of authors affiliated to INCT E and A.

The 76 articles retrieved and filtered from database are distributed in two periods: 2009-2014 (n = 56) and 2015-2020 (n = 20). Only 2 articles were indexed as reviews. English was the main language used (n = 56; 73.70%), followed by Portuguese (n = 20; 26.30%).

Figure 1: Number of articles retrieved with the biodiesel theme at INCT E&A and their intersections (2009-2020)

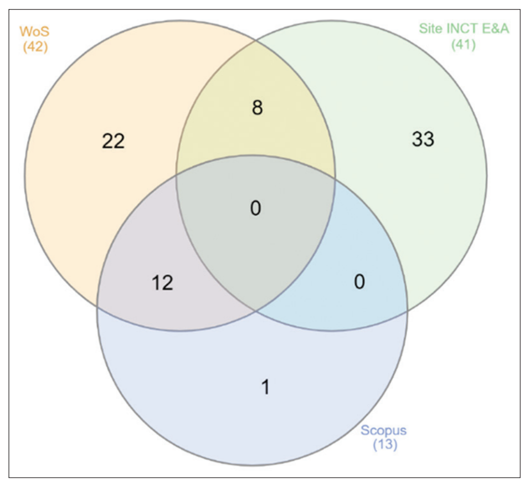
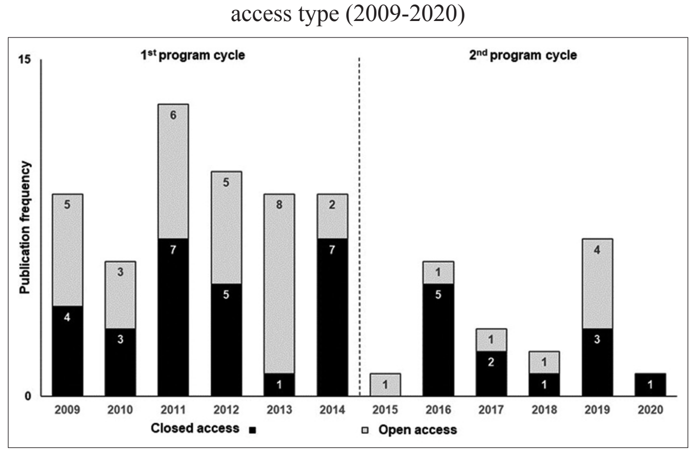


Figure 2: Number of articles published on biodiesel in INCT E&A by access type (2009-2020)



In Figure 2, it is possible to observe that researchers affiliated with INCT E and A have been publishing their research on biodiesel uninterruptedly since 2009. The publications peak took place in 2011 (n = 9; 17.11%), contributing to the program first cycle that concentrated 73.68% of publications. As of 2015, the number of published articles has dropped to an average number of 3 publications/year.

The decrease in research may have occurred due to a worsening of political and economic crisis that started in 2015, which culminated in impeachment of the President of the Republic in 2016, causing changes in managers in S and T agencies, budget cuts and priorities redefinition, affecting the funding of INCT institutes (Morel and Hauegen, 2017). Amid this turbulence in Brazil, the spending on scientific research has peaked to R$ 13.97 billion in 2015, followed by a gradual drop to R$ 5 billion in 2020 (Westin, 2020). As a result, the CNPq has an unpaid debt of about 30% of resources approved for the INCTs (Barreiro, 2020).

Figure 2 also shows how publications are disseminated in terms of access type. Out of the 76 articles, 39 (51.32%) were published in 19 restricted access journals, followed by 37 (48.68%) published in 15 open access journals. Overall, 28 (36.84%) articles were published in 7 national journals, all of which were open access. The average number of articles per journal was 2.24, showing a dispersion in research results' communication. The main journals are listed in Table 1.

Eight journals are listed in the JCR, two of which are Brazilian journals: Journal of the Brazilian Chemical Society (n = 8) and *Química Nova* (n = 5). The journal *Revista Virtual de Química* is also highlighted in Chart 2, which launched a special issue dedicated to INCT E and A in 2011, with four articles dedicated to research on biodiesel.

Overall, 66 (86.84%) articles are indexed in WoS, revealing researchers preference for publication in journals indexed in this base. Because of this, these articles were used to identify interaction pattern of different research areas according to WoS category classification.

Figure 3 shows a density map where it is possible to observe a strong interaction between the areas of multidisciplinary chemistry, chemical engineering, and energy and fuels, reinforcing the opinion of (Quintella et al., 2009) that chemistry permeates the entire biodiesel chain, being essential for its economic, environmental and technological viability.

Articles' acknowledgments were also analyzed because they offer an alternative path for funded research study, allowing to examine relationship between subsidies provided and registered knowledge production, in addition to revealing possible hidden collaborations of a non-financial nature that contributed to scientific production (Alvarez and Caregnato, 2018). Since 2018, the Coordination for the Improvement of Higher Education Personnel (Capes), a foundation within the Brazilian Ministry of Education, has made acknowledgment mandatory (Ministério da Educação, 2018).

In the database, 183 mentions of thanks for financial support were found in 53 (69.74%) articles, making an average of 3 mentions per article. The most cited funders were: Brazilian National Council for Scientific and Technological Development or CNPq (n = 54; 29.51%); Capes (n = 31; 16.94%); Funding Authority for Studies and Projects or Finep (n = 22; 12.02%); and State Research Support Foundations, especially FAPESB (n = 20; 10.93%) and FAPESP. Mentions of thanks for funding to the European Social Fund, the Portuguese Foundation for Science and Technology, and companies such as Petrobras were also identified.

27 non-financial acknowledgments were also identified, directed to teachers, laboratories and companies for: samples availability, technical and instrumental, intellectual and even moral support, revealing a hidden collaboration network that contributed to the works' production.

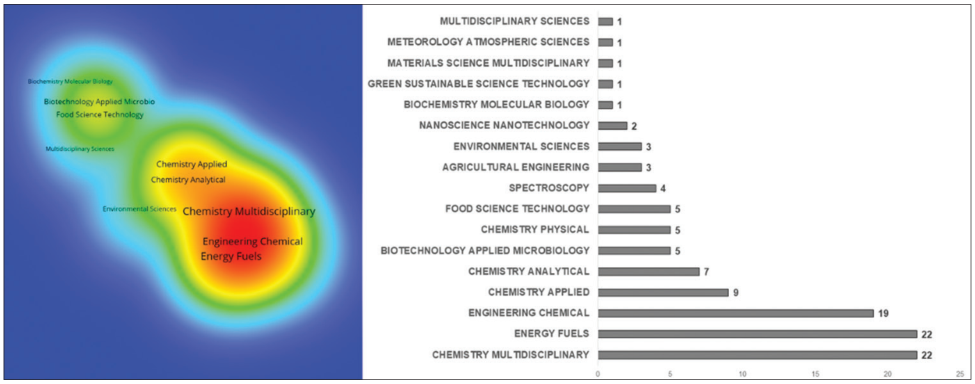
Finally, the number of institutions that participated in researches on biodiesel in partnership with INCT E and A was also collected (Figure 4). In all, 48 institutions were identified, among universities, research institutes and private companies from six countries, comprising Brazil, Portugal, USA, Belgium, Colombia and Tanzania. The strong interaction between UFBA

Table 1: Main periodicals used in research dissemination on biodiesel at institute of science and technology for energy and environment E and A (2009-2020)

Serial number	Title	QTT	Impact fator (2019)	Area/WoS quartile	Type*	Country
1	Fuel	8	5.578	Energy and Fuels (Q1) Chemical Engineering (Q1)	RA	England
2	Journal of the Brazilian Chemical Society	8	1.339	Multidisciplinary chemistry (Q3)	OA	Brazil
3	*Revista Virtual de Química*	6	-	-	OA	Brazil
4	*Cadernos de Prospecção*	5	-	-	OA	Brazil
5	Fuel Processing Technology	5	4.982	Química Aplicada (Q1) Energy and Fuels (Q2) Chemical Engineering (Q1)	RA	Netherlands
6	*Química Nova*	5	0.668	Multidisciplinary chemistry (Q4)	OA	Brazil
7	Energy and Fuels	4	3.421	Energy and fuels (Q2) chemical engineering (Q2)	RA	USA
8	Microchemical Journal	4	3.594	Analytical Chemistry (Q1)	RA	Netherlands
9	Biomass and Bioenergy	2	3.551	Agricultural Engineering (Q1) Energy and Fuels (Q2) Biotechnology and Applied Microbiology (Q2)	RA	England
10	Spectrochimica Acta Part B-Atomic Spectroscopy	2	3.086	Spectroscopy (Q1)	RA	England

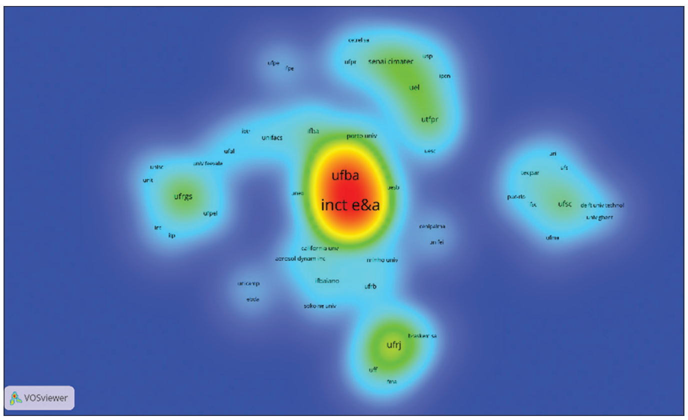
*Type: RA OA. Source: Prepared by the authors based on collected data from journal citation reports. RA: Restricted access, OA: Open access

Figure 3: Main identified WoS subject categories



Source: Prepared by the authors based on collected data from WoS core collection (2021). Note: Each of the 66 articles was indexed in two WoS categories on average

Figure 4: Institutions involved with INCT E&A in biodiesel research



Source: Prepared by the authors based on collected data from WoS core collection (2021)

and INCT E and A was expected, as this university is the institute's headquarters.

3.2. Analysis of Co-Authorship Indicators

After applying a deduplication process, 212 authors were found (average of 2.79 articles per author), with 111 (50.94%) female authors and 104 (49.06%) male authors. The authors were linked to 48 institutions, in which 31 of them were members of INCT E and A. UFBA concentrated 51.61% of the researchers affiliated to the institute.

Productivity of all authors was analyzed and it was found that 139 (65.57%) authors produced only one document, followed by 37 (14.45%) authors who produced 2 articles, 20 (9.43%) authors who produced between 3 and 4 articles and 16 (7.55%) with more than 5 articles produced, accounting for 38.82% of the publications.

All 76 articles were co-authored and many authors signed more than one article, resulting in a total of 407 co-authors. Articles with 6 co-authors (n = 19) was the most common. The lowest pattern of co-authorship was formed by 2 co-authors (n = 5) and the highest with 11 co-authors (n = 1). Table 2 presents the number of works co-authored by researchers directly affiliated to INCT E and A.

Overall, the average number of authors per document (collaboration index) was 5.29 and the average collaboration coefficient was 0.79, very close to 1. It indicates a strong pattern of co-authorship (Maia and Caregnato, 2008), which is to be expected for a multi-institutional and interdisciplinary program. In Figure 5, the collaboration coefficient remains above 70%, even with the drop in publications number observed during the 2nd cycle of the program, an indication of its existence.

3.3. Visualization and Analysis of the Co-Authorship General Network (2009-2020)

A co-authorship network represents a prototype of evolving complex networks with a non-trivial topological connection structure, which can be analyzed statically or dynamically (Barabási et al., 2002; Barabási and Pósfai, 2016; Newman et al., 2006).

Based on this assumption, undirected networks formed by circles and lines were created for the respective analyses. Each circle in a network represents an author and each line indicates a co-authorship relationship between two connected authors. Circles size indicates co-authored articles number, while the distance between two circles provides a proximity indication. Line thickness reveals "ties", that is, the thicker the line, the greater the relationship strength between the authors.

A co-authorship general network with research on biodiesel at INCT E and A from 2009 to 2020 is composed of 212 authors with 821 co-authorship relationships, distributed in 4 components (Figure 6a). The network formed only by authors affiliated to the institute (Figure 6b) has 31 authors and 43 co-authorship relationships, distributed in 8 components.

As it is a multi-institutional and interdisciplinary program, it was expected a greater integration between authors affiliated to INCT E and A, which would contribute in number reduction of components or even in a single component formation in researches on biodiesel.

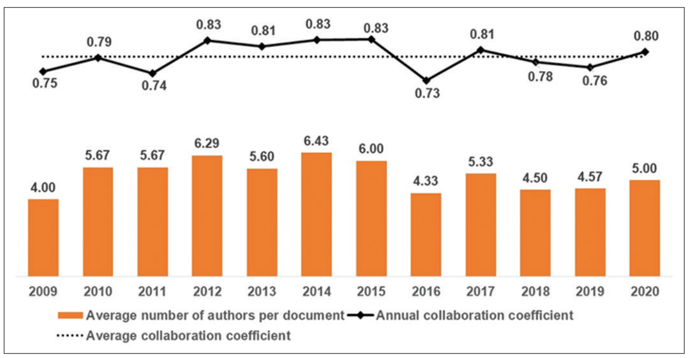
Overall network density was 0.037, while network density of authors affiliated with the institute was 0.092, indicating that these networks are weakly connected. Nodes' connections of both networks have an average degree of 7.745 and 2.774, respectively.

Table 2: Co-authorships number related to biodiesel research established by institute of science and technology for energy and environment E and A Researchers (2009-2020)

Name	Number co-authorships	Name	Number co-authorships
Antônio Mangrich** (UFPR)	1	Leonardo Teixeira** (UFBA)	12
Artur Mascarenhas (UFBA)	1	Lílian Guarieiro (CIMATEC)	6
Carine Alves (UFBA)	2	Luiz Carvalho (UFBA)	2
Cláudia Zini (UFRGS)	1	Márcia Silva (UFRGS)	2
Claudio Mota** (UFRJ)	13	Marcos Bezerra (UESB)	1
Cristina Quintella (UFBA)	13	Maria Solci (UEL)	6
Daniel Borges (UFSC)	1	Maria das Graças Korn (UFBA)	9
Daniele Santos (UFBA)	2	Maria Vale** (UFRGS)	1
Ednildo Torres** (UFBA)	1	Mauro Korn (UFBA)	1
Egídio Guerreiro (CIMATEC)	13	Pedro Pereira** (UFBA)	1
Elina Caramão** (UFRGS)	6	Pérola Vasconcellos (USP)	2
Geovani Brandão (UFBA)	1	Rennan Araújo (UFBA)	1
Gisele Rocha (UFBA)	8	Rosângela Jacques (UFRGS)	2
Heloysa Andrade (UFBA)	4	Silvio Melo (UFBA)	2
Jailson Andrade* (UFBA)	11	Wilson Lopes (UFBA)	1
Laíza Krause (UNIT)	3		

*INCT E and A coordinator, **Management committee members. Source: Prepared by the authors based on available data in: http://www.inct.cienam.ufba.br/quem-somos and http://inct.cnpq.br/web/inct-e-a/pesquisadores. Access on 10/02/2021. INCT E and A: Institute of Science and Technology for Energy and Environment

Figure 5: Annual evolution of the collaboration index and the collaboration coefficient (2009-2020)



Source: Prepared by the authors

The 1st and main component of the general network is formed by 146 (68.87%) authors and 598 (72.84%) co-authorship relationships. It brings together the majority of researchers directly affiliated to INCT E and A (n = 23; 74.19%) and also linked to 8 different institutions: UFBA (n = 15), SENAI CIMATEC (n = 2), and USP, UFSC, UFPB, UFPR UESB and UEL (n = 1). These 23 researchers (Figure 7) gave an inter-institutional network character and supported most of the research on biodiesel at INCT E and A.

The second largest component (n = 34; 16.04%) has 6 (19.35%) researchers affiliated to the institute and UFRGS (n = 5) and UNIT (n = 1). Then comes the third (n = 25; 11.79%) and fourth (n = 7; 3.30%) components. Both of them have only one researcher affiliated to INCT E and A and to UFRGS and UFBA, respectively.

Regarding cluster formation, the Association Strength method (Waltman et al., 2010) with a 0.80 clustering resolution was applied in VosViewer, resulting in 15 clusters or communities (Figure 6) with their own sets of research subjects, which may be unique, complementary or even overlapping. Clusters 1, 2, 3, 4, 5, 7, 8 and 9 stand out as they house the most productive researchers affiliated with INCT E and A (Chart 3).

Clusters number also indicates research topics diversity related to biodiesel within INCT E and A scope, involving from production residues use such as glycerin (Mota et al., 2009, 2016), inorganic and organic contaminants analyzes and quality control (Cazarolli et al., 2012; Quadros et al., 2011), vehicle emissions evaluation from biodiesel and mineral diesel mixture (Ferreira et al., 2013; Guarieiro et al., 2014), to biodiesel technological prospection (Quintella et al., 2009).

3.4. Topology of the Co-Authorship General Network

Topological analysis was performed from a structural analysis of the 1st component, which houses 68.87% of the connected authors, through application of Watts and Strogatz method (WATTS; STROGATZ, 1998) in order to identify a small world structure network, in which most connections are established between the closest vertices and the average shortest path between any of two vertices does not exceed a small number of vertices.

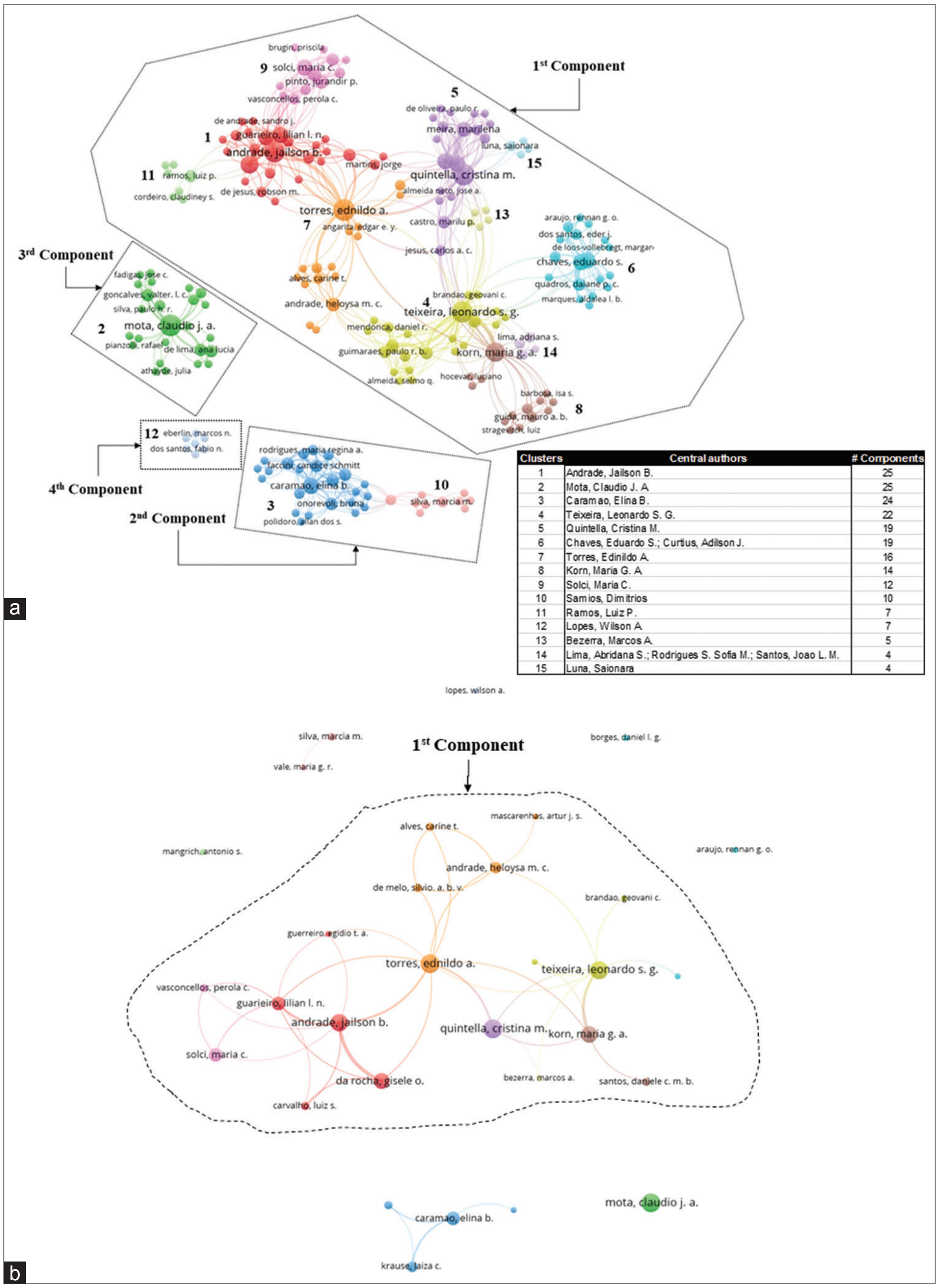
In order to do this, a random network of similar size to the 1st component was created, using the model proposed by (Erdös and Rényi, 1960). Then, the average shortest paths and agglomeration coefficients of both networks were compared.

Agglomeration coefficient obtained in the random network (0.023) was much smaller than agglomeration coefficient of the 1st component (0.869), while the average shortest paths of both networks were similar (random network = 3.610 and 1st component = 3.059), indicating existence of the small world structure in the network investigated in this study. Therefore, it is an efficient network for transmission of information and resources among its participants.

Another metric based on network topological analysis concerns degree centrality in order to know connections number established by the authors, identifying the most influential ones.

In the analyzed network, it was observed that degree distribution is not equal (Figure 8) and fits well to a power law ($P(k) \sim k^{-\gamma}$,

Figure 6: (a) Co-authorship General Network (2009-2020). (b) Co-authorship general network only with researchers affiliated to INCT



Clusters	Central authors	# Components
1	Andrade, Jailson B.	25
2	Mota, Claudio J. A	25
3	Caramao, Elina B.	24
4	Teixeira, Leonardo S. G.	22
5	Quintella, Cristina M.	19
6	Chaves, Eduardo S.; Curtius, Adilson J.	19
7	Torres, Edinildo A.	16
8	Korn, Maria G. A	14
9	Solci, Maria C.	12
10	Samios, Dimitrios	10
11	Ramos, Luiz P.	7
12	Lopes, Wilson A	7
13	Bezerra, Marcos A.	5
14	Lima, Abridana S.; Rodrigues S. Sofia M.; Santos, Joao L. M.	4
15	Luna, Saionara	4

Source: Prepared by the authors

where k>0 and γ>0), indicating that it fits the scale-free network model, resistant to random or accidental failures, but extremely vulnerable to coordinated attacks.

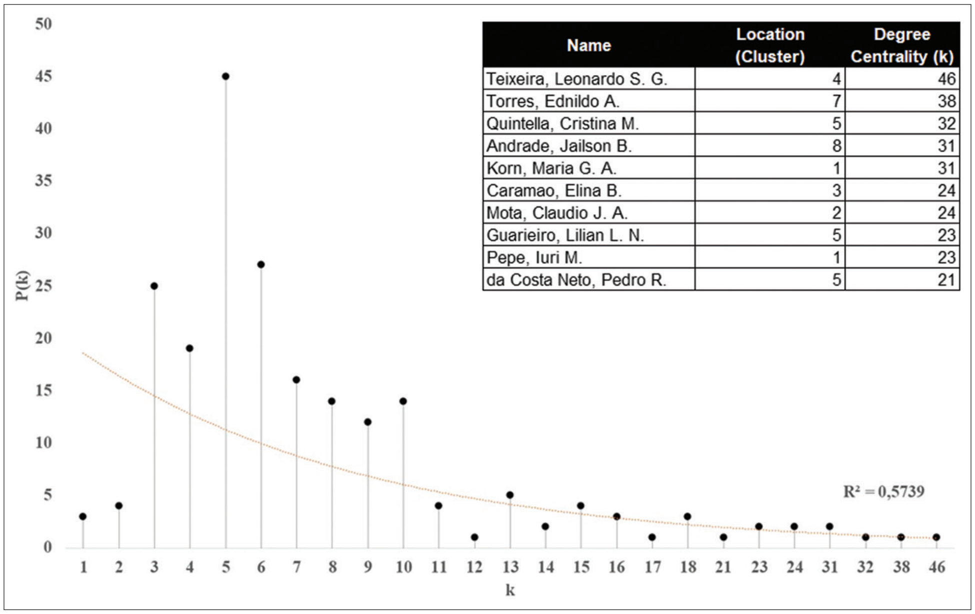
Figure 7 shows the authors who published the most in partnership with other authors, having a connection number that far exceeds network average degree ($\mu = 7.745$). These authors are the network hubs and they were selected taking into account the sum of network average degree plus two standard deviations.

Hubs can increase their number of connections as a new researcher enters the network, because they tend to connect with the most connected author(s). Thus, a network evolution is governed by preferential binding (Barabási and Pósfai, 2016).

Furthermore, it is assumed that the authors selected as hubs are influential researchers, with active relationships with other high-level authors and resources holders to carry out research, for example: among ten authors with the highest degree centrality, there are five management committee members and the INCT E and A coordinator (Table 2).

As degree centrality does not always capture vertex importance, betweenness centrality was used to identify authors who contributed the most to the network functioning, and which would cause more impact if they were removed from it. The eigenvector

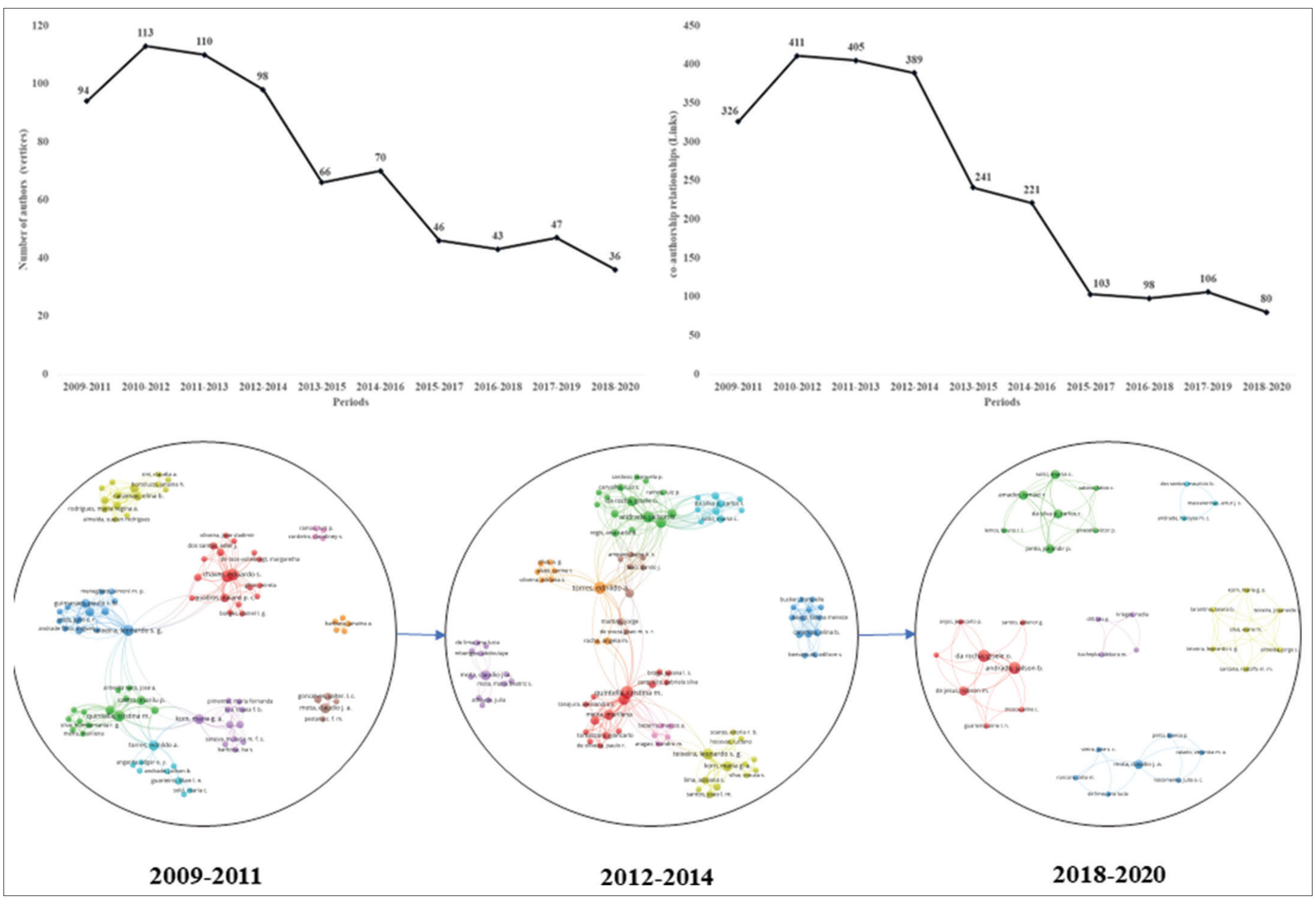
Figure 7: Degree distribution of the co-authorship general network (2009-2020)



Name	Location (Cluster)	Degree Centrality (k)
Teixeira, Leonardo S. G.	4	46
Torres, Ednildo A.	7	38
Quintella, Cristina M.	5	32
Andrade, Jailson B.	8	31
Korn, Maria G. A.	1	31
Caramao, Elina B.	3	24
Mota, Claudio J. A.	2	24
Guarieiro, Lilian L. N.	5	23
Pepe, Iuri M.	1	23
da Costa Neto, Pedro R.	5	21

Source: Prepared by the authors

Figure 8: Evolution of mobile co-authorship networks (by triennium)



Source: Prepared by the authors

centrality was also calculated to indicate an author importance in terms of his relationship with other relevant authors in the network. Both centralities were calculated from the 1st component.

Altogether, 44 (30.14%) of the authors of the 1st component had some intermediation degree of co-authorship relationships, but few of them had a high degree, making the distribution a power law type. Six of the ten authors with a high intermediation degree are in the identified hubs group, highlighting: Ednildo A. Torres, Leonardo S. G. Teixeira, Cristina Quintella and Jailson Andrade. They represent main bridges between distinct clusters (Figure 6).

In the case of eigenvector centrality, eight of the ten hubs identified have the highest indices of this metric and the aforementioned authors occupy the first positions when it comes to establishing links to other relevant authors in the network.

3.5. Dynamic Analysis of the Co-authorship General Network

In order to verify dynamically the co-authorship general network development, 10 networks with 3-year mobile intervals were built to cover the entire analysis period. Figure 8 clearly shows a reduction of authors and authorship relationships numbers, also exemplified in three different networks, the last one being less dense and fragmented.

Comparing the two program cycles (2009-2014 and 2015-2020), it was possible to infer that the network entered a rapid decline process soon after first cycle end, which was also verified in published articles number on biodiesel by INCT E and A researchers (Figure 2).

When checking the number of works co-authored by the hubs (Figure 7) between the program's first and second cycles, it was observed that four hubs of the 1st component did not produce any articles. All the others showed a significant reduction in the produced articles number, with emphasis on the two authors with the highest degree and intermediation centralities, who reduced their respective productions by around 81%.

As the co-authorship network fits the scale-free network model, this hubs demobilization had an effect of a "coordinated attack" that contributed to the network fragmentation and affected established inter-institutional partnerships. Only 8 (16.33%) of the 48 institutions identified in this research collaborated in articles production in the last triennium (2018-2020) of the second cycle.

4. CONCLUSION

In this article, production and articulations of 31 INCT E and A researchers with 181 co-authors from 48 institutions in 76 articles related to biodiesel research from 2009 to 2020 were analyzed, through scientometric analysis, and complex and social networks.

The scientometric analysis provided an overview of biodiesel researches carried out by INCT E and A researchers and provided a series of information that deserves to be highlighted.

The search strategy used in data collection revealed that publications number involving biodiesel theme produced by researchers affiliated to INCT E and A is 13.43% higher than that registered in the INCT E and A repository (http://inct.cnpq.br/web/inct-e-a) or in evaluation reports. This undersizing was caused by institution's name indexing errors by the authors, which can harm the program's evaluation since many funding agencies use bibliometric and scientometric indicators to release funds.

There was a high level of collaboration between researchers from different research domains. However, the biodiesel theme attracts less and less attention from INCT E and A researchers, which led to a considerable reduction in published articles number between the first and second cycles of the program. Factors such as budget cuts in R and D, departure of researchers affiliated to the program or even lack of interest in the subject may have contributed to the drop in publications number.

The analysis of acknowledgments of a non-financial nature present in the articles revealed a hidden collaboration that contributed to the works production, involving laboratories and other researchers. The co-authorship network analysis revealed, in an intuitive and friendly way, a hidden structure of researchers involved with the biodiesel theme that could not be captured by traditional research methods.

The network consisted of 4 components and 15 clusters with thematic affinities. Its largest component gathered 74.19% of the 31 researchers directly affiliated to INCT E and A. These researchers gave an inter-institutional network character and supported most of the research on biodiesel.

The topological analysis showed that the network fits the scale-free network model, where few researchers concentrate most of co-authorship reactions and presents a small world characteristic, which makes it efficient in transmitting information and resources among its participants.

When dynamically comparing the co-authorship network, there was a significant reduction in articles production by authors with the highest degree, intermediation and eigenvector centralities, causing the network fragmentation in the program 2nd cycle, and also affecting established inter-institutional partnerships number.

Demobilization of the INCT E and A biodiesel research network took place during the period in which Brazil chose biofuels as a strategy for decarbonizing transport matrix through the National Biofuels Policy (RenovaBio) (Presidência Da República, 2017).

Not by chance, the MCTI's science, technology and innovation plan for renewable energies and biofuels classifies the need to strengthen INCT E and A and RBTB as essential to help overcome technological challenges that will need to be faced in order to increase biodiesel share in national energy matrix in the coming years (MCTIC, 2018).

Finally, analyzes presented here are not exhaustive, as they were limited to biodiesel research, published in peer-reviewed articles. However, the strategy of collecting information, scientometric analysis, and complex and social networks can be used throughout INCT E and A production and other research institutes, helping managers of these institutes in an effective planning of research activities.

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