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SUSTAINABLE INNOVATIONS IN BIOFUELS IN BRAZIL AND THE SUBSTITUTION OF FOSSIL FUELS: A SYSTEMATIC LITERATURE REVIEW

INOVAÇÕES SUSTENTÁVEIS EM BIOCOMBUSTÍVEIS NO BRASIL E A SUBSTITUIÇÃO DOS COMBUSTÍVEIS FÓSSEIS: REVISÃO SISTEMÁTICA DA LITERATURA

BRUNA BARBIERI
https://orcid.org/0009-0007-4751-5668 / http://lattes.cnpq.br/0983284602329477bru_barbieri16@hotmail.com
Universidade Tecnológica Federal do Paraná, Francisco Beltrão – Paraná

ANDRIELE DE PRA CARVALHO
https://orcid.org/0000-0002-0266-8595 / http://lattes.cnpq.br/8290738827565231 / andrieled@utfpr.edu.br
Universidade Tecnológica Federal do Paraná, Francisco Beltrão – Paraná

MICHELE DI DOMENICO
https://orcid.org/0000-0001-8204-4821 / http://lattes.cnpq.br/4911805253362036/ micheled@utfpr.edu.br
Universidade Tecnológica Federal do Paraná, Francisco Beltrão – Paraná

ABSTRACT

Given the growing global concern with the increase in terrestrial temperature due to the unrestrained emission of greenhouse gases, solutions have been sought to minimize the environmental and social damage caused by them. One of the best options currently available is biofuels, which are renewable and sustainable and have various applications. In this context, this study aimed to systematically analyze the published studies on new biofuels, time of energy transitions, factors that influence the development and diffusion of technologies capable of replacing fossil fuels, advantages, and disadvantages of each application, in addition to the main trends and gaps in the area in Brazil. The articles were searched in the Science Direct database using the keywords “biofuel AND sustainable innovation AND Brazil AND multi-level” and filtering by category review articles and research articles. One hundred and twenty-six articles were obtained, which were analyzed for objectives, methodology, main results, conclusions, links with sustainable innovation, and the year of publication. The results showed that there is a large focus of research on traditional renewable energy sources, such as ethanol, biomethane, kerosene, and hydrotreated vegetable oil, in addition to the fact that most studies are of the qualitative type. Nonetheless, there has been a significant increase in publications after 2015, mainly justified by creating the Sustainable Development Goals and RenovaBio. Thus, the importance of obtaining new sources and processes for biofuels is highlighted and, in this way, achieving a development that encompasses environmental, social, and financial benefits for all related parties, as well as for the population in general, because there is still a large research gap in the area, and further incentives and investments are necessary for research, development, implementation, and dissemination of biofuels.
Keywords: biofuels; sustainable development; Brazil; renewable energy.

RESUMO

Diante da crescente preocupação mundial com o aumento da temperatura terrestre, devido a emissão desenfreada de gases do efeito estufa, buscam-se soluções para minimizar os danos ambientais e sociais

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causados por estes. Umas das melhores opções disponíveis atualmente são os biocombustíveis, visto que, são renováveis e sustentáveis. Nesse contexto, o presente trabalho objetivou analisar sistematicamente os estudos publicados acerca de novos biocombustíveis e fatores que influenciam o desenvolvimento e difusão de tecnologias capazes de substituir os combustíveis fósseis, vantagens e desvantagens de cada aplicação, além das principais tendências e lacunas na área. Para o levantamento dos artigos, realizou-se buscas na base de dados Science Direct, utilizando as palavras-chave: "*biofuel AND sustainable innovation AND Brazil AND multi-level*" e filtragem pela categoria artigos de revisão e artigos de pesquisa. Foram obtidos cento e vinte e seis artigos, que foram analisados considerando objetivos, metodologia, principais resultados, conclusões. A partir dos resultados obtidos, constata-se um grande foco de pesquisa em fontes energéticas renováveis tradicionais, como o etanol, biometano, querosene e óleo vegetal hodrotratado, além da maioria dos estudos serem do tipo qualitativo. Ainda, observa-se um aumento significativo no número de publicações após 2015, justificado, principalmente, pela criação dos Objetivos do Desenvolvimento Sustentável e do RenovaBio. Assim, destaca-se a importância de obterem-se novas fontes e processos para biocombustíveis e, dessa maneira, alcançar um desenvolvimento que englobe benefícios ambientais, sociais e financeiros para todas as partes envolvidas, assim como para a população em geral, visto que, ainda existe uma grande lacuna de pesquisa na área e são necessários mais incentivos e investimentos na pesquisa, desenvolvimento, implantação e difusão dos biocombustíveis.
Palavras-chave: biocombustíveis; desenvolvimento sustentável; Brasil; energias renováveis.

1 INTRODUCTION

There is a growing concern about the reduction of oil reserves, rising oil prices, environmental pollution, and climate change driven fossil fuels. Because of this, the use of biofuels has shown to be viable from the environmental, economic, and social points of view as a renewable energy source with lower environmental impacts (SALLET; ALVIM, 2011).

In Brazil, the use of biofuels began in the 1920s with the addition of ethanol to gasoline. Nevertheless, it was only in 1931 that Decree No. 19,717 was issued, officially adding sugar cane as fuel to gasoline. In the 1970s, the Federal Government created the National Alcohol Program (Proálcool), which established the necessary conditions for expanding this biofuel (SIMÕES, 2021).

The Proálcool program was created in 1975 to reduce the country's dependence on oil since the first oil crisis occurred in 1973. In 1978, the first cars running on alcohol were introduced, and in 1983, over 90% of the vehicles sold ran on this fuel. In 2005, the National Program for Biodiesel Production and Use was launched to stimulate social inclusion and regional development and encourage fuel use with less environmental impact. Additionally, advancing in the area 2010, the first experimental flights were made with aviation biokerosene in Brazil, and in 2013, the first commercial flight with this biofuel was completed (DELGADO; SOUSA; ROITMAN, 2017).

Regarding legislation in this sector, the Law regulating biofuels was published in 2011, and in 2014, the one that presents specifications for Alternative Aviation Kerosenes. In the next year,

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legislation was published regarding the specification of biomethane, and the last milestone consisted of the creation of RenovaBio in 2016 (DELGADO; SOUSA; ROITMAN, 2017). In this sense, RenovaBio seeks to expand the use of all biofuels in Brazil, reduce greenhouse gas emissions, and meet the responsibilities enshrined in the Paris Agreement (UBRABIO, 2017).

Nevertheless, in the search for greater protection of the environment and climate and to ensure that the population can enjoy peace and prosperity, Brazil and numerous other countries, together with the United Nations, defined the Sustainable Development Goals. Among the goals is access to clean and sustainable energy and actions against global climate change (UNITED NATIONS BRAZIL, 2021).

In order to achieve a cleaner and more sustainable energy matrix, with the goal of sustainable innovation, which consists of a development considering financial issues, but with a concern for the environment and society, some new biofuels, which help reduce the emission of greenhouse gases, and other substances harmful to nature and human health, have the potential for increased production and use, among them can be mentioned aviation biokerosene, biomethane and hydrotreated vegetable oil (HVO), among others (DELGADO; SOUSA; ROITMAN, 2017).

Aviation biokerosene is an alternative aviation fuel from biomass, with vegetable oils and sugar materials as its main raw materials, and its main advantage is the reduction of greenhouse gas emissions (SILVA, 2019). Biomethane is obtained through biogas purification and has characteristics similar to natural gas, which allows it to be mixed with it. It can be produced from organic residues from farming and forestry activities, as well as from landfills and sewage treatment plants, and it can generate thermal and electrical energy in cars to replace vehicular natural gas. It can also partially substitute diesel in trucks, tractors, and agricultural machinery (DELGADO; SOUSA; ROITMAN, 2017). Hydrotreated vegetable oil is a biofuel that uses the existing oil refinery infrastructure, is sulfur and aromatic-free, is compatible with diesel engines, and has good storage stability (PINTO, 2013).

Given the above, this study covers new biofuels on the Brazilian market, such as aviation biokerosene, biomethane, and hydrotreated vegetable oil, amongst others, through a systematic literature review on digital platforms using the analysis method developed by Denyer and Tranfield (2009) to trace a panorama of the current situation and establish which are the main gaps in the sector, verifying which biofuels have more significant potential for growth, investment, and substitution of fossil fuels, consequently causing, a decrease in environmental impacts.

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2 THEORETICAL FRAMEWORK

2.1 Biofuels

According to the National Petroleum, Natural Gas and Biofuels Agency (2020a), biofuels can partially or completely replace fuels derived from petroleum and natural gas in combustion engines or other types of energy generation and are derived from renewable biomass.

With the goal of a more sustainable development that presents lower environmental impacts, this is a branch of significant growth in Brazil and worldwide. The main reasons are to reduce dependence on oil since it is a finite source and may become scarce in a few years, causing price instability and uneven distribution (GALEMBECK; BARBOSA; SOUSA, 2009). In addition, it seeks to reduce and control the emission of greenhouse gases in the atmosphere to minimize global warming (LEITE; LEAL, 2007).

The main biofuels produced in Brazil are currently ethanol, which is derived from sugarcane, and biodiesel, produced from vegetable oils or animal fats. In 2019, ethanol production was 36.0 billion liters, an increase of 11% over the previous year. In contrast, biodiesel production in the same period was roughly 9.3 billion liters (EPE, 2020a). Moreover, in 2019, Brazil's share of biofuels in the transport sector stood at 25.1%, a significant portion that shows that the country has great potential for expanding the use of renewable sources in its energy matrix (Figure 1).

For figures, tables, graphs, and other visual aids, you should use the template below, which is in accordance with the 2021 ABNT updates:

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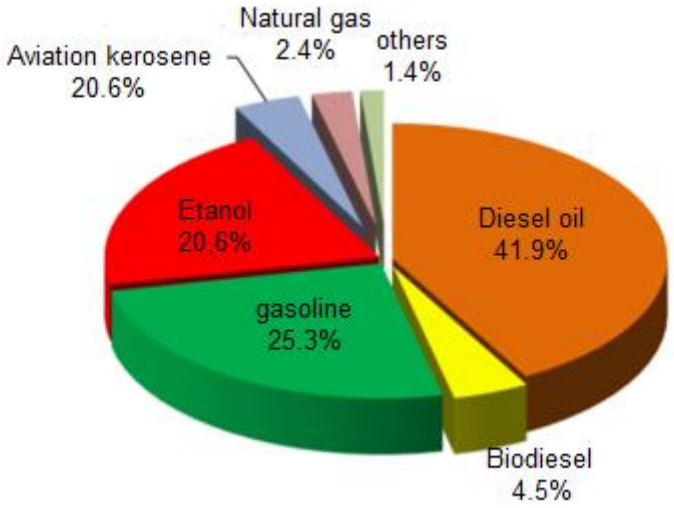
Figure 1 - Energy consumption in transportation in 2019



Source: EPE (2020b)

According to the National Petroleum Agency (ANP) (2020b), in 2020, Brazil had 410 biodiesel and ethanol production facilities, mainly concentrated in southeastern and midwestern Brazil since these locations have the most significant raw material production for these biofuels.

In 2019, the National Biofuels Policy (RenovaBio), instituted by Law No. 13,576/2017, was enacted; it is an initiative of the Federal Government that aims to increase the production and participation of biofuels in the national transportation energy matrix and, thus, establish annual national decarbonization targets for the fuel sector. Furthermore, there is a tendency for new biofuels to enter the Brazilian energy matrix (ANP, 2020c).

Given the concerns with sustainable development and the incentives offered by the Federal Government, such as RenovaBio, renewable sources have increased in the Brazilian transportation sector to replace fossil fuels, as illustrated in Figure 2.

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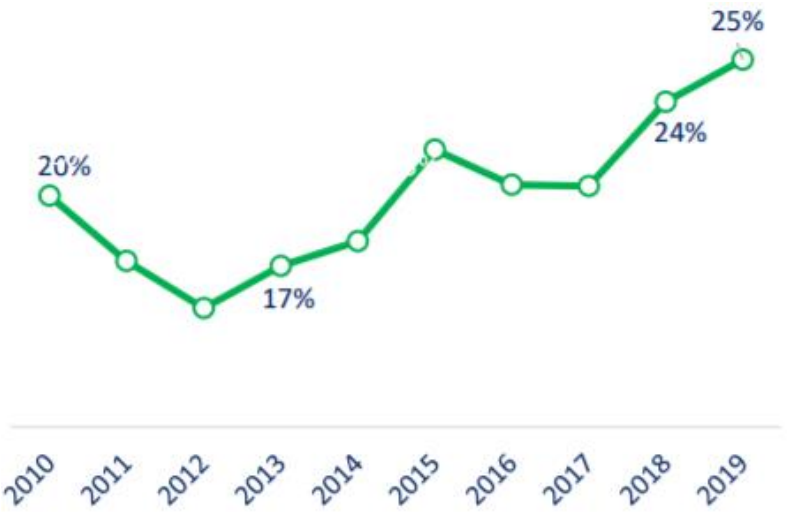
Figure 2 - Participation of renewable energy in transportation



Source: EPE (2020b)

Various studies have been conducted to search for innovative biofuel solutions to enable global expansion in the sector. Some biofuels, such as HVO, BioQAV (aviation biokerosene), and biomethane (EPE, 2017), deserve to be highlighted.

2.2 Sustainable Innovation

In the 1970s, due to the scarcity of some natural resources, a concern arose among companies concerning forms of growth not compromised by this lack of materials; from this, it developed the interest and the search for sustainability (sustainable development) (SILVA et al., 2012). In 1987, the World Commission on Environment and Development published the Brundtland Report, which defines sustainable development as “meeting the needs of the present without compromising the ability of future generations to meet their needs.” Sustainable development is based on decreasing the use of raw materials and products and consequent increase in reuse, coupled with the participation of society, to balance the economy and the environment (CORREIA; DIAS, 2016). In addition, the insertion of a circular economy occurs and is based on the regeneration of capital value, which seeks to reinsert products as raw materials into production chains, thus achieving a greater balance between economic and environmental issues (GONÇALVES; BARROSO, 2019).

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Hence, sustainable innovation was elaborated by companies integrating growth with environmental, social, and financial benefits (SILVA et al., 2012). In fact, evidence has shown that organizations cannot base their competitiveness only on economic performance, since it is essential to evaluate social and environmental aspects for long-term evolution (SILVEIRA et al., 2016).

Moreover, in order to achieve sustainability, continued education is necessary on the part of companies and the population as a whole, and for this, actions that assist in the transformation of human thinking should be implemented, aiming at increasing the protection of the environment (BITENCOURT; SILVA; SANTOS, 2018).

2.3 Greenhouse Gases

Greenhouse gases are gaseous substances such as water vapor, carbon dioxide, ozone, and methane, among others, which are naturally present in the atmosphere and are responsible for absorbing part of the infrared radiation emitted by the sun and reflected by the Earth's surface, that is, they have the property of retaining heat (IBICT, 1999).

One of the gases most concerning scientists is carbon dioxide (CO_2); it acts as a greenhouse covering the Earth, warming the planet and allowing the existence of human life. However, its emission has increased significantly due to human activities and the use of fossil fuels, and as it remains in the atmosphere for about 100 years, the amount present is becoming larger and larger, amplifying the Earth's temperature (IBICT, 1999).

Another gas responsible for the greenhouse effect is methane, which usually originates from extraction processes and the use of fossil fuels or the anaerobic decomposition of organic substances (TOLENTINO; ROCHA-FILHO, 1998). It has a residence time of approximately ten years, much less than CO_2, but due to its greater warming potential, it causes about 28 times more impact than carbon dioxide (SEEG, 2020). In addition, it is responsible for roughly 18% of global warming, and its atmospheric concentration has increased significantly, showing a growth of 0.9% per year (LEGNAIOLI, 2021).

In 2019, Brazil's gross greenhouse gas emissions increased by 9.6% increase, releasing 2.17 billion tons of carbon dioxide equivalent into the atmosphere, driven mainly by deforestation in the Amazon, followed by agriculture and the energy sector, with the latter accounting for 19% of the country's total emissions, this is mainly due to the activation of gas-fired thermoelectric plants and the increased use of diesel (SEEG, 2020).

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2.4 National and global agreements and policies regarding climate change and atmospheric emissions

Every year since 1995, nations have held world conferences to analyze the climate changes occurring on Earth and suggest solutions to curb them. Currently, one of the main agreements assumed by the countries is the Paris Agreement, which is a global treaty adopted in 2015 at the United Nations Climate Change Conference (COP) to establish measures to mitigate climate change and greenhouse gas emissions from 2020 onwards, in addition to reducing the increase in the planet's temperature to a value lower than 2 ºC. To this end, the countries made national commitments to achieve these purposes, with Brazil committing to reduce its greenhouse gas emissions by 37% in 2025, and by 2030 the reduction will be 43% (MCTIC, 2021).

In 2021, the new COP26 took place in Glasgow to renew the responsibilities assumed by the participating countries, in addition to establishing more ambitious targets and thus curb the effects of climate change caused by the emission of toxic gases into the atmosphere and meet the objectives of the Paris Agreement. Brazil has revised its emissions reduction target from 43 to 50% by 2030, reiterating its intention to be climate neutral by 2050. In addition, it announced non-binding agreements regarding zero deforestation and a 30% reduction in methane gas emissions by 2030, as well as pacts for forest recovery (AGÊNCIA CÂMARA DE NOTÍCIAS, 2021).

3 METHODOLOGICAL PROCEDURES

3.1 Research Type

This is a systematic literature review on sustainable innovations in biofuels. According to Denyer and Tranfield (2009), a systematic review is a methodological process that seeks and selects existing studies and, from there, examines the information to obtain clear considerations about issues that are or are not known. The study by Xavier et al. (2017) defined the steps for the systematic literature review based on the method of Denyer and Tranfield (2009):

The formulation of the research question;

Study location;

Study selection and evaluation;

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Analysis and synthesis;

Reporting and use of the research results.

3.2 Data Collection

The Science Direct platform was used as a database to locate the studies for this work using review articles and research articles as a filter, not including book chapters, encyclopedias, and editorials, among others. The keywords were defined based on the objective of the work, and the following were used: biofuel AND sustainable innovation AND Brazil AND multi-level.

3.3 Data Analysis

After collecting the data with the help of the table in Appendix A for listing the studies, each article's titles and objectives were analyzed to verify which ones discuss the theme biofuels and sustainable innovation. Subsequently, the article was read in its entirety, and the study was carried out based on some categories, namely the methodology, the fuel researched, the approach to the concept of sustainable innovation, the main results obtained, and the research gaps found. Based on this, an Excel spreadsheet was prepared for the organization and evaluation of the data, based on the table in Appendix B.

This in-depth study sought to present a solid understanding of the current knowledge about biofuels, presenting information and identifying the main gaps in this field, to verify the major difficulties in expanding and using new sources and processes in the area of biofuels, combined with sustainable innovation.

4 RESULTS AND DISCUSSION

According to the Science Direct database used in this study and the method of surveying the articles, one hundred and twenty-six articles were analyzed. All papers presented subjects that reached the theme of renewable energy sources, although only a few contained the connection with sustainable development and biofuels and had Brazil as a focus, thereby being important themes for the study. Thus, the following sections show the results obtained from the analysis, based on the filtering methodology used in the articles, by title, subject, and objectives

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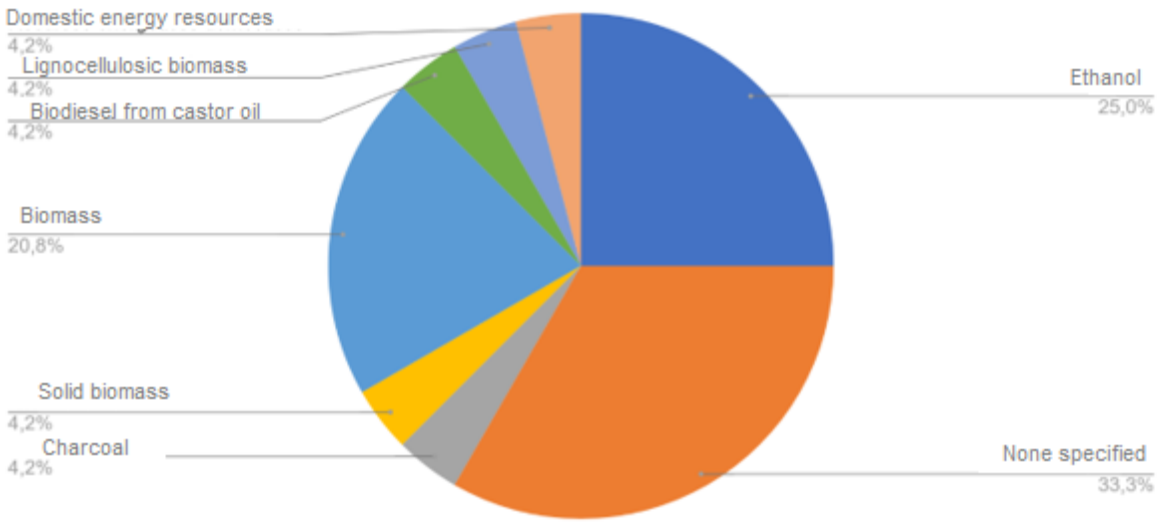
4.1 Subject matter and objectives of the articles

When reading the articles, 21 of the 126 covered the subject of biofuels in Brazil; however, many of them analyzed governance models, policies, algorithms, and implementation time, among others, of energy sources that already exist and have been implemented for some time, and few studies focused on developing new biofuels.

4.2 Analysis of energy sources

By analyzing the data from the 21 selected articles, a chart was constructed showing which renewable energy sources were most addressed in the studies; this is presented in Figure 3.

FIGURE 3 - ENERGY SOURCE ADDRESSED IN EACH ARTICLE



Source: Own authorship (2021)

By evaluating Figure 3, one can observe that most of the articles, 6 in total, had ethanol as the research focus, followed by biomass (5 articles), with some addressing a specific type, while others discussed various sources of biofuels (none specified), corresponding to 8 articles. This shows how research still focuses on more traditional and well-known sources and methods of biofuel use without exploring the benefits that the use of new materials and processes could bring.

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Silveira and Johnson (2015) reported that Brazil's ethanol program is a global example of success in replacing oil in the transportation sector, which justifies why research is primarily focused on this fuel since it provides several relevant information about how to succeed in the deployment of new technologies.

Nevertheless, it is noted that it is essential to introduce feedstocks that are not derived solely from food and that require large areas of land for planting because, in this way, the viability and sustainability of biofuel are uncertain and cause financial and food insecurity (KOKOSSIS; YANG, 2010).

Kokossis and Yang (2010) presented an option and discussed second-generation biorefineries, which cover additional processing paths with a wide range of raw materials to be applied, such as waste. Some suggested processes are the hydrogenation of vegetable oils to generate green diesel, and the thermal or chemical process, depending on the purpose, to break down lignocellulosic biomass, which according to Dragone et al. (2020), is mainly composed of proteins, acetic acid, and lignin, with potential for manufacturing valuable bioproducts.

4.3 Analysis of the methods

According to Coelho (2019), methods can be classified according to the approach and procedures used; the approaches are divided into qualitative and quantitative and the procedures are classified as:

Experimental research: in which an object of study is chosen, then the variables that can influence it are selected, and ways of controlling and observing the effects of the variables are established;

Literature review: based on published materials, such as books, and scientific articles, among others;

Documentary research: done with materials that have not received analytical treatment;

Field research: based on investigations made by collecting data from people, complementing the bibliographic and/or documental research;

Case study: covers a deep and exhaustive study of one or a few objects to seek in-depth detail of the subject.

The 21 articles were then classified after analyzing the methods applied in each one (Figure 4)

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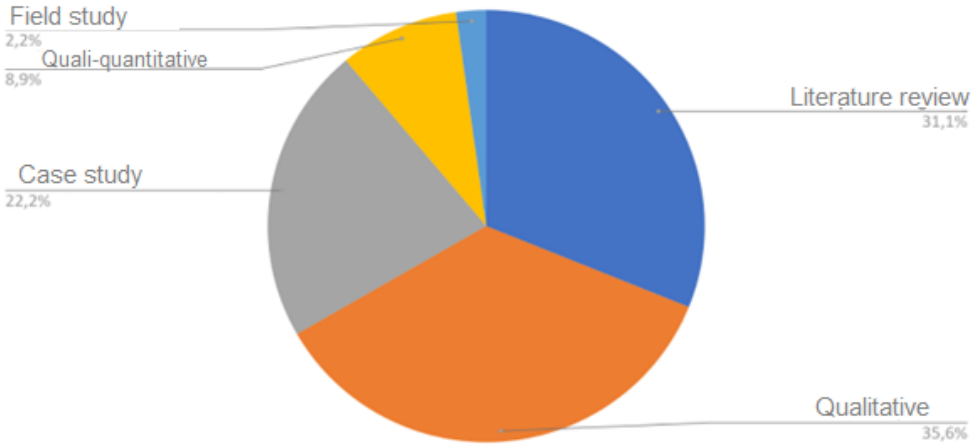
Figure 4 – The method applied in the articles



Source: Own authorship (2021)

Figure 4 shows that most articles (16 in total) have a qualitative approach, and none used only a quantitative approach. Regarding the procedure used, 14 articles conducted literature reviews and 10 applied case studies.

4.3.1 Qualitative method and literature review

German et al. (2017) reviewed theoretical perspectives on change management, investigated the factors responsible for discordance between policy and program objectives and actual outcomes, the underlying factors of successful change management, and synthesized evidence from the literature on the effectiveness and sustainability of national biofuel programs, identifying indispensable rationales for biofuel governance. Leite (2021) used this method to observe variables that are influenced by biomass and related to sustainability. They also examined the adversities and limitations that have hindered the implementation of biomass as an important energy source.

Moreover, Ingrão et al. (2018) highlighted the importance of academic research and its contributions to the bioeconomy, dividing the study into five research themes: biomass, biomaterials, and bioenergy; agriculture; forestry; food and feed production and packaging; and miscellaneous

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applications. Clausen and Fichter (2019) analyzed 130 cases in various environmental product and service fields, obtaining critical information for sustainability, environmental, and innovation policies.

Kokossis and Yang (2010) applied the qualitative method for first- and second-generation biofuels and observed the difficulties in optimizing their supply chains and a position that the total systems approach could benefit from important and lasting contributions. They also studied the role of systems technology in stimulating innovation and solving complex problems that can arise in biorefineries.

Qadir et al. (2021) employed a qualitative literature review to characterize obstacles to the transition to renewable energy and highlight quick implementation strategies. The researchers noted that it is crucial that all aspects of transitioning to renewable energy, such as policy formulation, financing mechanisms, and storage technologies, be assessed for effective carbon emission reduction.

Dragone et al. (2020) examined recent innovations and strategic directions for developing advanced biorefineries with the goal of large-scale deployment of biorefineries, targeting the valorization of protein, acetic acid, and lignin from biomass. Kretschmer and Peterson (2009) explored the literature on bioenergy/biofuel policies, analyzed the advantages of computable general equilibrium models, and compared them to partial equilibrium models. Lastly, Lazaro et al. (2021) analyzed the links within the water, energy, and food nexus by categorizing thematic dictionaries composed of word vectors, and from this, they built the qualitative model applied to the corpus using Natural Language Processing techniques.

4.3.2 Qualitative method and case study

Bennertz and Rip (2018) employed qualitative method with a case study to study the history of automotive-energy infrastructure in Brazil and the influence of the interests of a modernizing developmentalist state with the resources of the sugar sector and the artifacts of the automotive sector. In addition, a perspective on the emergence and stabilization of infrastructure is presented.

Furthermore, Solomon and Krishna (2011) conducted three case studies, namely, the transition from oil to sugarcane ethanol in Brazil, the switch from oil-fired to nuclear electric power in France, and the attempt to replace foreign oil with a mix of domestic energy resources in the United

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States. In each case, the authors qualitatively ascertained factors influencing the transitions and their time frames.

4.3.3 Qualitative method, literature review, and case study

Silveira and Johnson (2015) chose as case studies the bioenergy transitions in Sweden and Brazil, comparing between the two cases and analyzing the causes that facilitated or hindered each transition; for this, they used the available literature on sociotechnical transitions, innovation systems, and systems approaches.

Meanwhile, Roy et al. (2013) explored the existing literature on efficient and effective fiscal instruments for the transition to low-carbon systems, studying how national government policies intervene and mobilize domestic financing to support energy transitions, thereby attracting public and private funds that help support transitions. Various countries from all regions of the globe were used as case studies.

Furthermore, Sovacool (2015) reviewed the literature on the timing of global and national energy transitions, employing ten case studies, which took 1 to 16 years to accomplish the energy transition and affected almost a billion people worldwide. In addition, Johnson and Silveira (2013) verified alternative transportation transition pathways, focusing on ethanol programs and policies in three countries (Brazil, Malawi, and Sweden). They analyzed a wide range of published literature and conducted interviews, discussions, and workshops with key actors. The study took nearly four decades and spanned three continents.

4.3.4 Qualitative-quantitative method

Florin et al. (2013) conducted northern Minas Gerais State as a case study; this region was chosen to verify the management decisions of farmers, industries, and policymakers that may interfere with the engagement of family farmers in producing biodiesel from castor oil. The researchers based their study on scientific literature that shows the barriers that must be overcome to make castor oil plant production viable in the region and thus increase the farmers' engagement in this sector.

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Moreover, Gross et al. (2018) provided an empirical review of the time elapsed from invention to widespread commercial use of various technologies and a conceptual and definitional discussion of the stages of innovation rooted in innovation literature. Furthermore, Hultman et al. (2011) selected cases, conducted interviews with experts, and analyzed the data on reasons that influence the significant transformation of energy technology in national and technological contexts. Three countries (Brazil, Sweden, and the United States) and two forms of energy (bioenergy and nuclear energy) were selected as case studies.

Nogueira et al. (2017) sought to look at the current experience in the evaluation of bioenergy systems and, from this, suggest a way forward to support policymakers in the process of implementing new sustainable bioenergy systems or evaluating existing ones; for this, the authors used a matrix of strengths, weaknesses, opportunities, and threats.

4.3.5 Other Methods

Sovacool (2011) collected data through interviews and field research in seven countries, along with four case studies, in order to examine programs and policies that have some influence on climate change and modern energy use. Never and Betz (2014) applied their study to Brazil, China, India, Indonesia, South Korea, Mexico, and South Africa to test the influence of domestic green industry, the proportion of fossil fuels to financial power, international bargaining position, and environmental civil society. For this purpose, they used a qualitative comparative analysis.

4.4 Analysis of the main results and conclusions of the studies

Upon analyzing the twenty-one articles, we observed that Lazaro et al. (2021) had, as a result, constructed thematic dictionaries of the existing scientific literature on ethanol and research focused on this area in Brazil based on natural language processing algorithms. German et al. (2017) found that minimum conditions are necessary for biofuel programs to be successfully implemented fairly and sustainably. They also concluded that the essential goal is to find ways to reduce global energy demand because sustainable development can only be achieved.

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Roy et al. (2013) realized that using fiscal instruments for policy interventions is responsible for generating domestic funding resources and support for low-carbon energy transitions. Azevedo et al. (2019) realized that sustainable development in the biomass field is related to economic, social, and environmental factors. Moreover, government policies are primarily responsible for decreasing the use of fossil fuels and instigating innovation and adherence to biofuels, thus causing climate change mitigation.

In addition, Johnson and Silveira (2013) also found that strong national policies, coupled with public and private actors, enable fuel transitions at distinct levels of economic development. Moreover, Gross et al. (2018) similarly noted that continued policy efforts in innovative technologies are indispensable, considering both research and development support and the time and effort required to implement low-carbon technologies in the market.

Silveira and Johnson (2015), in turn, concluded that it is vital that biomass be considered for various applications, such as fuel, fiber, and food. In addition, to achieve an energy transition that meets sustainability requirements, socio-technical changes supported by public and private institutions that have an interest in stimulating research, development, innovation, and the efficient use of resources are needed, as well as goals and policies capable of raising investments, creating market and infrastructure.

Dragone et al. (2020) also found that only with the pooling of knowledge of experts, academics, and industries, in addition to actions of all stakeholders and policymakers will it be possible to innovate and create new biorefineries. Despite various advances that have already occurred in the area and many biorefineries are already operating at a large scale, achieving sustainability still requires considerable improvements and the development of efficient and economically feasible technologies.

Bennertz and Rip (2018) understood that a country's energy history and the residue of knowledge about biofuel use carry important information about the development and use of renewable energy sources, which assists in searching for and deploying new biofuel technologies and sources. Meanwhile, Ingrao et al. (2018) realized that bioenergy is a crucial international research area, especially in bioeconomics. In addition, there is a growing interest in the influence of bioeconomy on the agricultural and forestry sectors, particularly in material processing alternatives in relation to production infrastructure to achieve sustainability.

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Hultman et al. (2011) identified key factors for change in the energy system, the main ones being domestic policy that had as objectives domestic economic competitiveness, energy security, rural development, and support for existing industries. In addition, other agents are the initial saturation in the technology and energy sector, the management structure of the private sector, political networks, and financial capacity.

Sovacool (2011) found that polycentric approaches to climate and energy governance can create an equitable, inclusive, informative, accountable, protective, and adaptive framework for achieving energy sustainability and security. Furthermore, he noted that policymakers generally seek solutions to energy and climate problems through technology development but realized that having the right policy environment is also necessary.

In his other study, Sovacool (2015) concluded that rapid transitions could occur in the energy system. However, they are only noticeable when certain factors are considered, such as how significant the change is, the society in which it occurs, the energy resources and services it will influence, and the context in which it happens. Furthermore, Solomon and Krishna (2011) also made points about energy transitions, finding that they can occur within a few decades. However, a global transition in the energy sector is unlikely to happen in short periods because there is currently no agreement among all nations about the advantages of such changes.

In addition, Qadir et al. (2021) noted that funding and a lack of awareness about renewable energy sources and their benefits and applications are one of the main difficulties for renewable energy transitions. Thus, a cleaner and more sustainable future can be achieved only with incentives in these areas.

Never and Betz (2014) noted that only having a considerable amount of energy from renewable sources is not enough to achieve sustainable development without harming the environment if the use of fossil fuels continues to increase. The country's financial capacity is insufficient.

Lastly, Florin et al. (2013) identified conditions for achieving sustainable, social, and regional development — improvements in the technical management of the crop, reduction of cash constraints at the farm level, and innovations in the production chain so that, in this way, farmers have economic, social, and environmental benefits, as well as industries and the general population.

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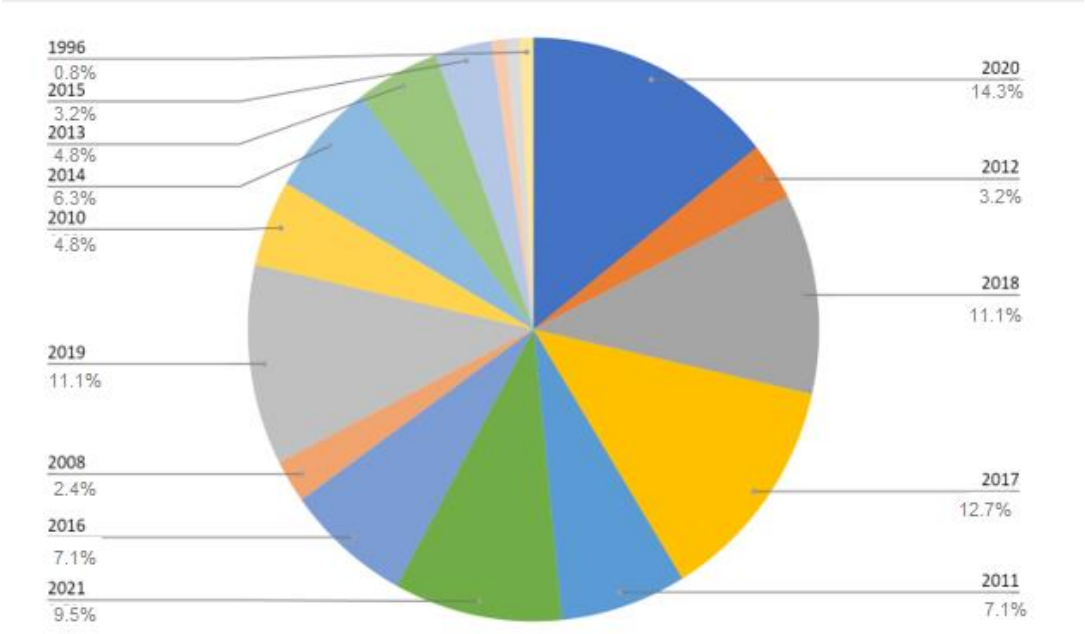
4.5 Analysis of the articles' year of publication

Figure 5 illustrates the relationship between the publication dates of the 126 articles analyzed.

Figure 5 - The articles' year of publication



Source: Own authorship (2021)

As shown in Figure 5, research has increased considerably in recent years, with over 50% of publications occurring from 2015 onwards. This shows that due to the increase in global concern about the emission of greenhouse gases and climate change, as well as the adoption of the Sustainable Development Goals in 2015 and the creation of RenovaBio in 2016, they contributed to encouraging researchers, universities, and private institutions to study issues related to biofuels and sustainable innovation, enabling greater knowledge on the subject and the main difficulties faced in this area.

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4.6 Trends and gaps in the field of biofuels

By analyzing the articles, it was possible to observe that one of the main gaps in biofuels is related to financing and awareness. Despite incentives, many individuals are still unaware of the benefits of renewable energy, which creates a barrier to the support and deployment of new sources, as individual and corporate investors are reluctant to invest in this field (QADIR et al., 2021).

Research by both public and private institutions is essential to improve the production, economic and sustainable efficiency of biofuels, and support from governments, since production, research, and development costs are sometimes high, making it difficult for the private sector alone to invest (ULHOA, 2013).

Other important points to be observed are the approach of new sectors and sources of biofuels, as well as the main factors influencing them (LAZARO et al., 2021). As well as the detailed study of the time from research development, market introduction, and diffusion of the use of the innovation, in addition to the analysis of technical or product complexity (CLAUSEN; FICHTER, 2019).

Furthermore, investments and incentives are needed in the area of modeling so that the problems related to biofuel production and trade become less severe and even disappear with time if the data obtained are more reliable because, currently, different models present disagreements in the results (KRETSCHEMER; PETERSON, 2009).

Given the analysis of the 126 articles, several contributions, trends, and gaps in the field of biofuels were noted:

Research on new sectors and sources of biofuels enables new methods to be developed, which are capable of bringing environmental, economic, and financial benefits to all stakeholders;

The evaluation of influencing factors in biofuel production;

The verification of economic and governance factors which hinder the development and deployment of new biofuel sources, such as high costs or barriers imposed by some governments;

A lack of investment in research and development, especially in developing countries.

The resistance to using due to food insecurity, caused by the production of biofuels from food, and also the substitution of land use for planting raw materials for them;

Analyze the benefits of cellulosic and lignocellulosic biomass materials, which are energy-rich and comprise a large part of biomass but are generally ignored and discarded.

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Although research into biofuels presents the gaps mentioned above, numerous factors contribute to its success. Thus, its implementation and development benefit the population, the government, and industries.

According to the Brazilian Agriculture and Livestock Company (EMBRAPA, 2011), implementing and producing biofuels is responsible for social inclusion, generating many jobs for the population, in addition to strengthening the national industry and agriculture, since it helps improve new technologies, increasing learning. Furthermore, concerning the environment, it contributes to reducing greenhouse gas emissions and improves air quality in large cities.

Furthermore, biofuels are renewable, environmentally friendly, natural, biodegradable, and have a wide variety of raw materials, and some types have greater lubrication capacity, which increases the useful life of engines (EMBRAPA, 2007). Hence, Table 1, based on the articles analyzed and cited in this article, points out the relationship of the main approaches to studies about biofuel in Brazil, containing the advantages, types of biofuels analyzed, and its status in the country.

Table 1 – The advantages and status of the objectives of the studies about the types of biofuels in Brazil.

Formulating a qualitative analytical model that goes beyond the three components of the water-energy-food nexus, incorporating other elements such as policy, innovation, governance, and labor to examine their effects as influencing factors and understand how long-forgotten synergies, trade-offs, and interconnections between sectors and between existing policies and institutions can become visible. This qualitative model was applied to the case of ethanol in Brazil.
Revisiting and expanding on the findings of recent policy papers and debates on biofuel performance to date in order to distill the lessons learned and draw on these lessons and the broader literature on change management and scalability to explore the implications for biofuel governance.
Contributing to the literature by bringing to it a concept of sustainability of countries in relation to biomass, to identify the main reasons that prevent biomass from being an important source of energy production and, therefore, of sustainable development of countries, that is, to identify some adversities and constraints associated with the production of bioenergy from biomass.

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Analyzing the transition paths at different levels of economic development for countries that have purposefully committed to encouraging a shift away from fossil fuels in the transport sector, three countries were chosen (Brazil, Malawi, and Sweden) to cover three different regions of the world and three different levels of economic development.
Concern with inserting new energy sources in the national matrix, starting from small producers, and observing how the management of natural resources is done.
Summarizing and discussing the latest innovations and strategic directions for advanced biorefinery development. The focus is acknowledging the value of non-carbohydrate components of biomass (protein, acetic acid, and lignin), local and tailored production of enzymes, big data analysis, and interdisciplinary efforts. The idea is to provide new knowledge and directions to support biorefineries' development and large-scale implementation.
Reviewing the historical development of the automotive-energy infrastructure in Brazil so that the most generalizable features are visible, focusing mainly on ethanol.
Highlighting the importance of academic research in documenting forms of biobased concepts, tools, technologies, education, and policies playing increasingly central roles in accelerating the transition to equity with post-fossil carbon-sustainable societies.
Analyzing previous transitions, the factors behind them, and their time frames. Three modern case studies are discussed: Brazil, which switched from an oil-based transportation system to one based on sugarcane-ethanol; France, which switched from oil-fired electricity to nuclear power; and the United States, which tried to switch from foreign oil to a mix of domestic energy resources.
Considering historical evidence for the time it took for various energy supply and end-use technologies to emerge from invention diffuse into the marketplace and achieve wide deployment.
Studying the energy transformations in bioenergy and nuclear energy in Brazil.
Reviewing the current experience in evaluating bioenergy systems and proposing a way forward to support policymakers in implementing new sustainable bioenergy systems or evaluating existing ones, especially for developing countries.
Conducting a comprehensive review of the tax instruments applied in all nations to facilitate low-carbon energy system transitions.

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Highlighting the central role of systems technology to promote innovation, visualize options, and support high-throughput computational experimentation, arguing that system tools are largely underdeveloped. In addition, describing opportunities for innovation in design, concept-level synthesis, and process integration.
Questioning polycentric approaches — those that mix scales, mechanisms, and actors — promotes equity, inclusion, information, accountability, organizational multiplicity, and adaptability that result in solving climate and energy-related problems. After explaining its case selection and research method, defining climate governance, and conceptualizing polycentrism, the study answers this question with cases related to electricity supply in Denmark, ethanol production in Brazil, small-scale renewable energy in Bangladesh, and off-grid energy use in China.
Providing a qualitative comparative analysis of the climate policy performance of seven emerging economies, divided into a time comparison of 14 cases. Testing the influence of the domestic green industry, the legacy of the traditional international negotiating position, the proportion of fossil fuels to financial capacity, and the influence of environmental civil society on changes in emission levels.
Reviewing the factors affecting the transition to renewable energy, outline the current state of renewable energy, and discuss barriers to renewable energy adoption faced by individuals, businesses, and government-related institutions. In addition, highlighting the importance of stakeholder participation in policymaking, offering alternatives for carbon taxation and global grid connectivity to achieve the transition to renewable energy.

Source: Own authorship (2021)

In view of the above, the field of biofuels is clearly of great importance and potential for growth. However, it is crucial for further advances in academic and industrial research along with financial and social support from governments and society in order to achieve sustainability.

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5 CONCLUSION

Biofuels are clean, sustainable, and renewable energy sources and are an essential means of achieving sustainable development, encompassing beneficial innovations in the environmental, social, and financial senses, and are an excellent option for replacing fossil fuels.

This study analyzed one hundred and twenty-six articles, selecting twenty-one most relevant to the research aim, addressing themes related to biofuels, especially in Brazil. Our findings revealed that, in general, the articles analyzed times of energy transition, advantages, and disadvantages of the introduction of biofuels in the national energy matrix, the main difficulties of innovation and implementation in the area, as well as the influence of non-government agencies, governments, and private institutions in encouraging the adoption of renewable energy sources.

Furthermore, most of the studies discussed ethanol, which shows that the main focus is still on known and employed sources in Brazil for a relatively long time, with its expansion occurring with the oil crisis in the 1970s. Nonetheless, with the dispute over sugarcane exports, it is clear that greater national renewable energy matrix diversification is essential. Less frequent findings also indicated a direction for developing research focused on biomethane, kerosene, and hydrated vegetable oil as renewable energy possibilities.

The results also showed that most articles employed a qualitative approach, making descriptive and inductive analyses of the data obtained to present their results. Given the study, the research deficiency on new biofuel sources stood out, in addition to the little incentive given to research and development in emerging countries, including Brazil.

Considering these data, future studies could address renewable energy sources that differ from conventional ones, which may pave new avenues of improvements in environmental preservation by employing materials with the potential to provide advantages for all stakeholders and the population in general, including the use of waste and/or lignocellulosic material and innovative processes that use structures designed and built to reduce spending for companies concerned with the environmental damage caused by fossil fuels.

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