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Research Article

# Biofuels and nanocatalysts: A Data Mining study

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**A myriad of scientific documents is produced annually on the most diverse topics. Thus, understanding the paths taken during scientific advances in a given area is often challenging to map, and scientific fortunes are hidden in these documents. Therefore, developing strategies for understanding advances in topics of interest is crucial for good scientific work. Among the most relevant themes of modernity, the use of renewable resources for the production of biofuels attracts the attention of several countries, constituting a vital part of the global geopolitical chessboard since humanity's energy needs will grow faster and faster. Fortunately, advances in personal computing associated with free and open-source software production greatly facilitate this work of prospecting and understanding complex scenarios. Thus, for the development of this work, the keywords biofuel and nanocatalyst were delivered to the Scopus database, which returned 1071 scientific articles. The titles and abstracts of these papers were saved in RIS format and submitted to automatic analysis via the Visualization of Similarities Method implemented in VOSviewer 1.6.18 software. Then, the data extracted from the VOSviewer were processed by software written in Python, which allowed using the network data generated by the Visualization of Similarities Method. Thus, it was possible to establish the relationships for the pair between the nodes of all clusters classified by Link Strength Between Items or Terms (LSBI) or by year. This approach allowed us to infer that the most recent pairs of terms associate the need to produce biofuels from oils produced by microorganisms and the use of cerium oxide nanoparticles to improve the performance of fuel mixtures by reducing the emission of hydrocarbons and NOx.**

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# Introduction

Biofuel is any material used to generate energy from organic biomass in internal combustion engines[1]. In the case of biofuels, the energy source is derived from biomass, which has stored the energy of the sun, in the case of vegetables, as chemical energy[2]. The biomass can be from several different sources, such as aquatic and terrestrial plants, forest and agricultural residues, vegetable oils, and municipal and industrial waste[3]. The main types of biofuels are biodiesel[4], biogas[5], bioethanol[6], biomethanol[7], and pure vegetable oil[8].

Despite the numerous advantages, such as environmental sustainability[9] and the potential to fully or partially replace fossil fuels[10], biofuels carry some disadvantages, such as pollution caused by intensive crops, high water consumption, the loss of biological diversity, and food habitats[11]. There is also a concern that the use of crops to produce biofuels would increase the price of agri-food products[12].

Thus, the development of more efficient methods for biofuels production is key to the best use of renewable energy sources, providing the desired transition from the consumption of petroleum-derived fuels to fuels from sustainable sources without the need to increase agriculture areas[13]. For this, the use of more efficient catalytic systems is promising[14][15]. Among them, the nanocatalysts are inorganic materials, such as semiconductors and metal oxides, which are the leading players in nanocatalysis[16][17][18][19][20][21][22][23]. Nanocatalysis bridges the gap between homogeneous and heterogeneous catalysis, allowing the advantages of both to be combined[24]. Nanocatalysts have a high surface area, increasing the contact between the reactants and the catalyst surface, allowing a significant increase in catalytic activity[25]. On the other hand, they are easily separable from the reaction medium due to their insolubility[26].

Among the most diverse uses of nanocatalysts are energy storage, fuel cell, medicine, modification of carbon nanotubes, biodiesel production, solid composite rocket propellants, water purification, and dyeing[27]. The present work deals with biofuels applications, introducing the result of a systematic search for the keywords "biofuels" and "nanocatalysts" in the Scopus database. This search returned 1071 documents, which had their titles and abstracts analyzed by clustering techniques via Machine Learning implemented in the VOSviewer software and deepened by data reprocessing using mainly the Pandas Python library. Results referring to the number of publications per year, area of knowledge, and country allowed drawing a global panorama. Besides that, the most recent association of terms among the analyzed documents occurs between "exhaust gas temperature" and "$CeO_2$ nanoparticles-dispersed water–diesel–biodiesel". Therefore, the collected data point to the direction of the most current scientific efforts to improve the quality of diesel engines, making them less polluting[28].

## Methods

Worldwide tendencies on research about "biofuels" and "nanocatalysts" were determined by mining data. All available information was retrieved and analyzed according to the following steps.

First, all articles related to research themes subscribed to the Scopus database were searched. Data from papers containing the term "biofuel and nanocatalyst" in the title, abstract, or keywords, using the key TITLE-ABS-KEY ("biofuels" AND "nanocat*") AND (LIMIT-TO (DOCTYPE , "ar")) were selected. Then, the gathered information was classified by the number of publications per year, area of knowledge, and country using the Scopus Database tools. The primary data files are available on GitHub (https://github.com/ftir-mc/Biofuel-nanocatalyst.git).

Then, the RIS file from Scopus was processed using the VOSviewer software, v. 1.6.18[29]. The bibliometric classification was made in the "overlay" and "network" modes. Additionally, the files were exported as NET and MAP files for the overlay and cluster classification, respectively. Data from MAP files were organized by cluster size and total link strength. The top-five nodes for each cluster were selected and plotted.

Finally, a software code was written in Python using mainly the Pandas[30] library. This code allows defining the terms (nodes) correlated with each other, pair to pair, initially registered numerically in the network file generated by VOSviewer. Then, it was possible to identify the nodes with the highest binding strengths (measured in joint counts of occurrences) and the nodes with the most recent annual mean values. In addition, the Euclidean distance between the nodes was calculated. These data are shown as Treemaps, generated by the Python module Plotly Express[31].

## Results

Figure 1 shows the evolution in the number of published documents on biofuel and nanocatalysts in the Scopus database.

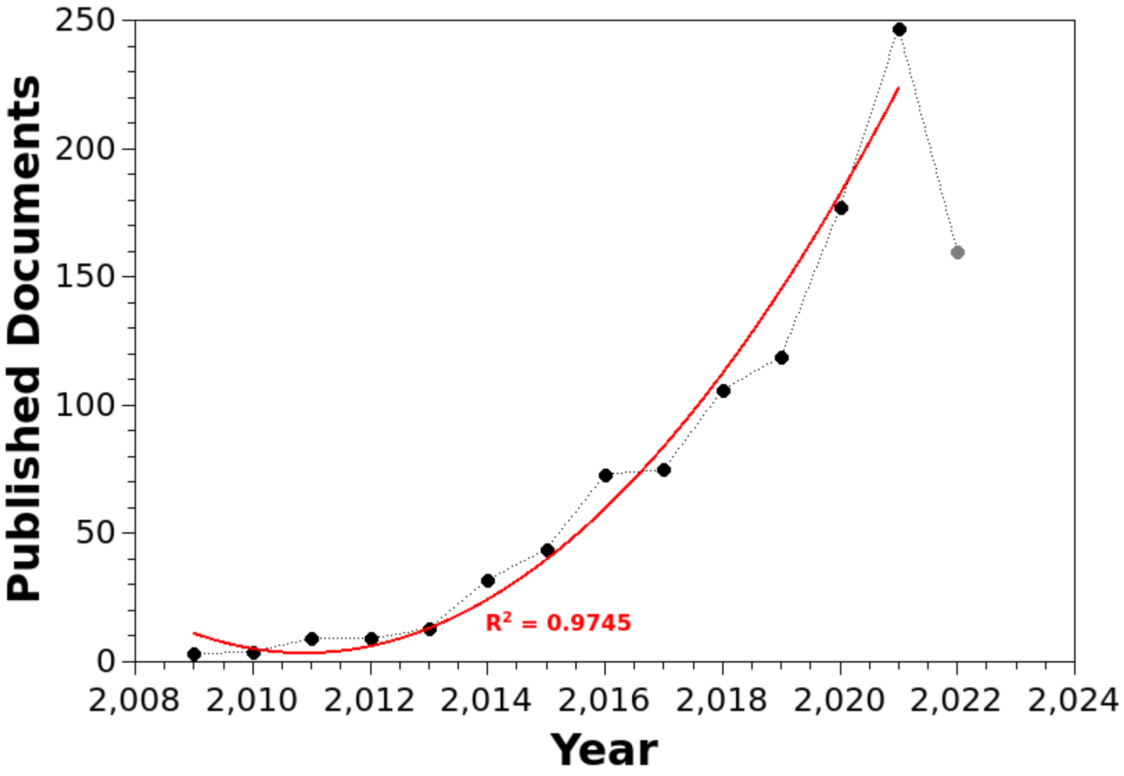

**Figure 1.** *Published documents per year from data retrieved from the Scopus database*

The first documents are from 2009. After that date and until 2021, the data trend is described by a polynomial function of order 2, with an $R^2$ equal to 0.9745. This result indicates that the Academy's interest in these topics has increased rapidly over the last few years. Thus, it is likely that the number of publications will continue to increase rapidly over the next few years.

Another exciting classification automatically offered by the Scopus database is the classification by knowledge area, shown in Figure 2.

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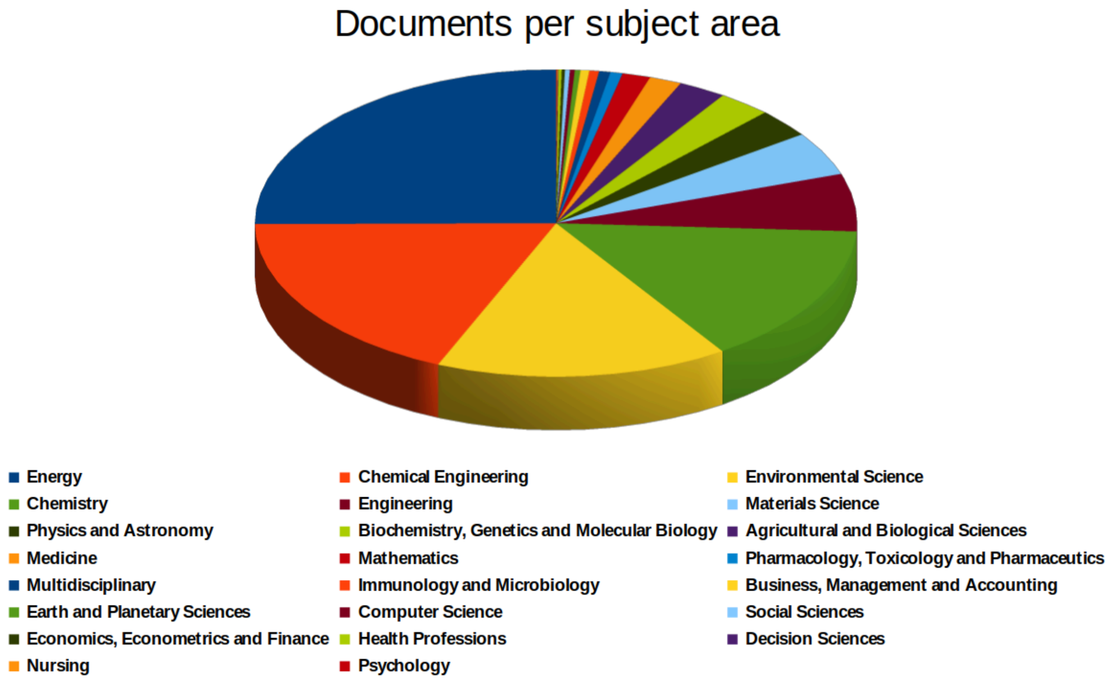

**Figure 2**. *Documents per subject area from data retrieved from the Scopus database*

Among the areas of knowledge, the most remarkable contributions came from Energy (579 documents), Chemical Engineering (427), Environmental Science (363), Chemistry (342), Engineering (140), Materials Science (106), Physics and Astronomy (69 ), Biochemistry, Genetics and Molecular Biology (66), Agricultural and Biological Sciences (59), and Medicine (40). The sum of the number of documents exceeds the total number of articles gathered in this research because each document can be in more than one knowledge area at the same time.

Regarding Journals, the most extensive contributions came from Renewable Energy (128 documents), Bioresource Technology (69), Fuel (63), Energy (30), ACS Sustainable Chemistry And Engineering (24), Biomass And Bioenergy (22), Energy Conversion And Management (20), Green Chemistry (18), Chemosphere (17), and International Journal Of Hydrogen Energy (17).

Figure 3 shows the countries that contributed the most to the theme.

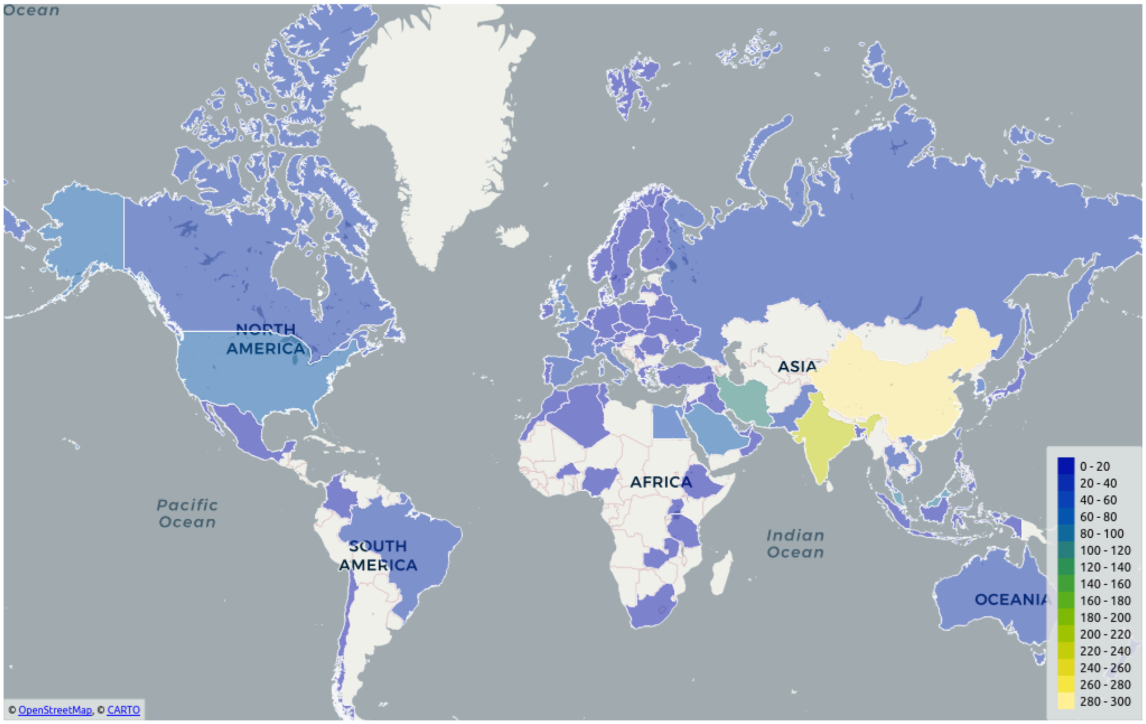

**Figure 3.** *Documents per country from data retrieved from the Scopus database*

The data extracted from the Scopus database has the following classification: China (296 documents), India (229), Iran (115), Malaysia (95), United States (78), Saudi Arabia (62), South Korea (45), United Kingdom (44), Egypt (42), and Brazil (38). These data make it clear that the most prominent players on the subject are China and India, countries with huge populations that need all possible energy sources, including renewable ones.

Although these facts about the main areas and the leading players are fascinating even from a geopolitical point of view, this is not the main focus of this work, which is interested in terms and associations of terms in the documents researched.

Therefore, the first strategy employed was constructing a word cloud using the words of titles and abstracts. The result is shown in Figure 4.

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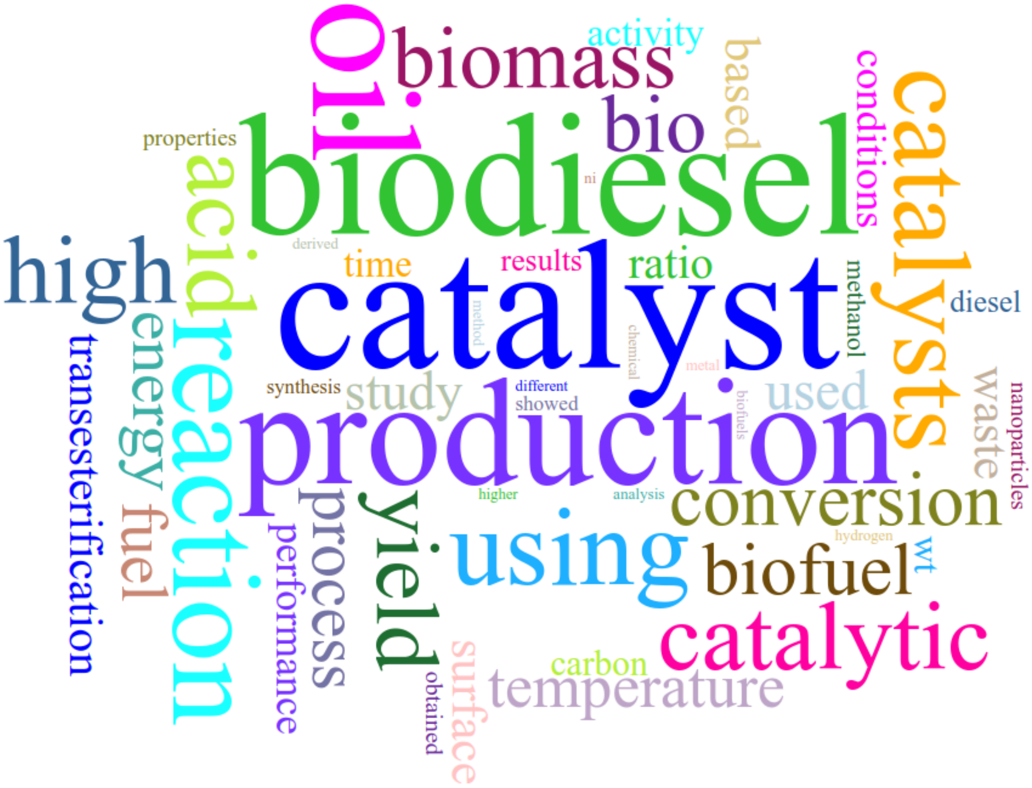
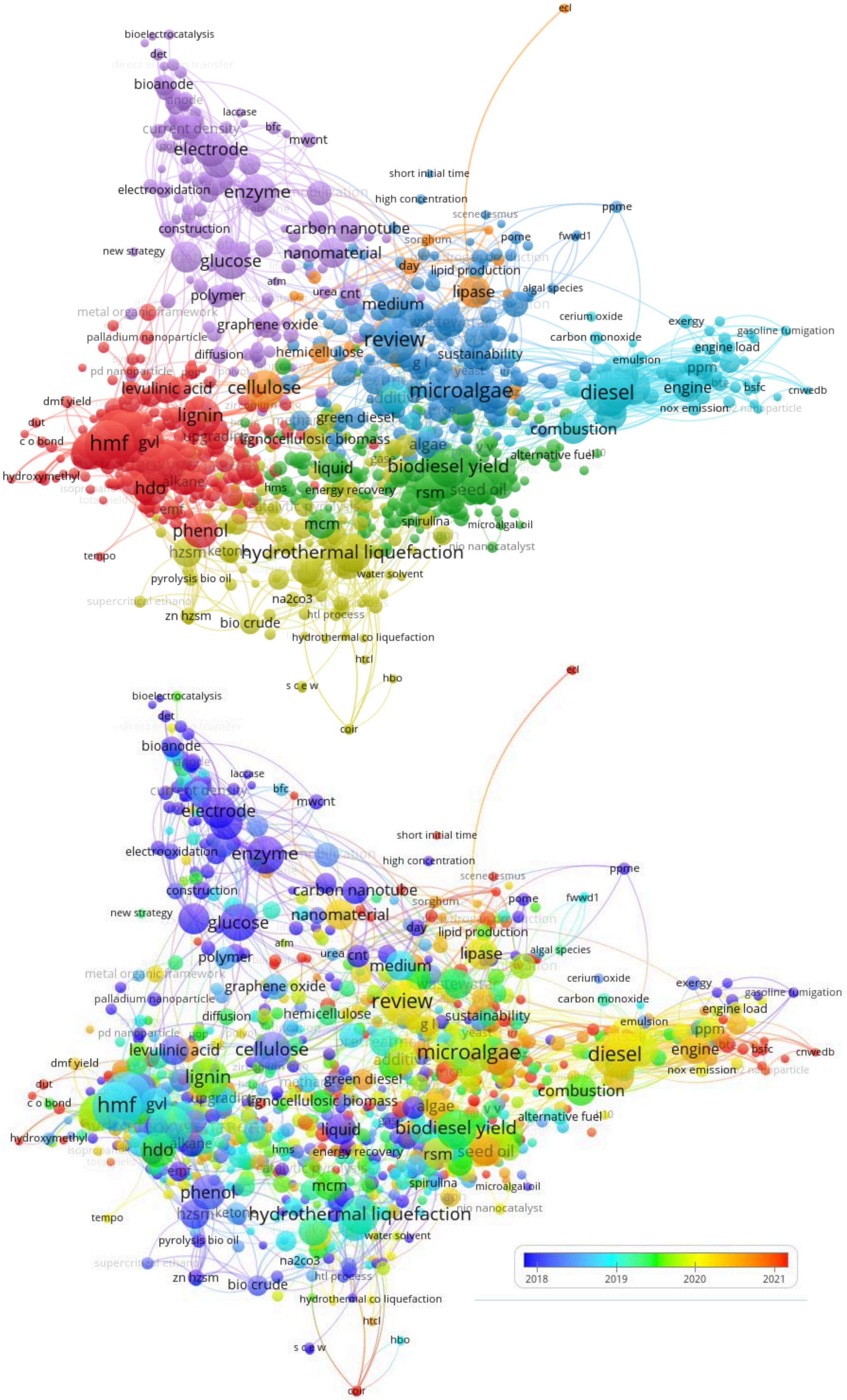


**Figure 4.** *Voyant Tools word cloud from titles and abstracts retrieved from the Scopus database*

The visual analysis of Figure 4 allows us to infer that the most frequent terms in the word cloud are catalyst, biodiesel, oil and production. The present analysis was done using Voyant Tools, indicating how many times these words are present in the text. More specifically, the most frequent words in the corpus[32] are catalyst (2054 times), biodiesel (1812), oil (1742), production (1483), and reaction (1182).

All this information is exciting and enriching but of little practical value. Therefore, improved tools are essential for understanding the context in which the topic of biofuels and nanocatalysts is inserted and where the technical-scientific focus is heading. Thus, the VOSviewer software allows a particular approach based on a method called VOS, meaning "*visualization of similarities*"[33]. Figure 5 shows the maps generated by the VOSviewer software.


ecl
bioelectrocatalysis
det
direct electron transfer
bioanode
anode
laccase
current density
bfc
mwcnt
electrode
electrooxidation
enzyme
immobilization
short initial time
high concentration
scenedesmus
ppme
construction
carbon nanotube
sorghum
pome
fwwd1
new strategy
glucose
nanomaterial
day
lipid production
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algal species
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metal organic framework
cerium oxide
graphene oxide
wastewater
exergy
palladium nanoparticle
carbon monoxide
gasoline fumigation
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hydroxymethyl
liquid
biodiesel yield
isopropanol
hdo
alkane
hms
energy recovery
rsm
seed oil
total yield
emf
catalytic pyrolysis
spirulina
microalgal oil
phenol
mcm
hzsm
ketone
hydrothermal liquefaction
nio nanocatalyst
tempo
water solvent
pyrolysis bio oil
supercritical ethanol
na2co3
zn hzsm
bio crude
htl process
hydrothermal co liquefaction
htcl
hbo
s c e w
coir
2018
2019
2020
2021

**Figure 5.** *VOS clustering map (top) and overlay (bottom) from titles and abstracts retrieved from the Scopus database*

VOSviewer generates a classification by grouping the keywords of the analyzed texts, and succinctly, the closer two terms are, the more significant the correlation between them. The cluster data generated by the software is a proximity map consisting of nodes (terms selected by relevance in the number of occurrences), such as Figure 5 (top), and clusters that contain these nodes. The second way of visualization is via the Overlay map [See Figure 5 (bottom)], which presents the same nodes as in the previous case, now sorted by age so that older terms are marked with cold colors while newer terms are in warm colors. Therefore, Figure 5 (top) demonstrates the existence of seven clusters, each one marked in its color. In turn, Figure 5 (bottom) shows all the most current nodes in orange-reddish tones.

Although functional and visually beautiful, the map representation has several overlays that make analysis difficult. Thus, the developed code seeks to overcome this disadvantage. The first information provided is regarding the top five nodes of each cluster. Thus, the top five nodes per cluster are hmf or 5-hydroxymethylfurfural (cluster 1; Occ. 147), hydrogenation (cluster 1; Occ. 141), hydrodeoxygenation (cluster 1; Occ. 114), lignin (cluster 1; Occ. 95), dmf or 2,5-dimethylfuran (cluster 1; Occ. 81), biodiesel yield (cluster 2; Occ. 97), seed oil (cluster 2; Occ. 60), liquid (cluster 2; Occ. 59), rsm or Response Surface Methodology (cluster 2; Occ. 58), oil molar ratio (cluster 2; Occ. 57), microalgae (cluster 3; Occ. 130), review (cluster 3; Occ. 124), medium (cluster 3; Occ. 57), wastewater (cluster 3; Occ. 53), pretreatment (cluster 3; Occ. 50), hydrothermal liquefaction (cluster 4; Occ. 87), htl or Hydrothermal liquefaction (cluster 4; Occ. 66), bio oil yield (cluster 4; Occ. 55), hzsm or protonated zeolite catalysts (cluster 4; Occ. 51), mj kg (cluster 4; Occ. 42), enzyme (cluster 5; Occ. 89), glucose (cluster 5; Occ. 82), electrode (cluster 5; Occ. 76), biofuel cell (cluster 5; Occ. 68), oxidation (cluster 5; Occ. 60), diesel (cluster 6; Occ. 126), blend (cluster 6; Occ. 89), emission (cluster 6; Occ. 87), diesel engine (cluster 6; Occ. 79), combustion (cluster 6; Occ. 60), cellulose (cluster 7; Occ. 85), lipase (cluster 7; Occ. 63), hemicellulose (cluster 7; Occ. 27), day (cluster 7; Occ. 18), viz or videlicet (cluster 7; Occ. 13). The top five nodes per cluster are also shown in Figure 6.

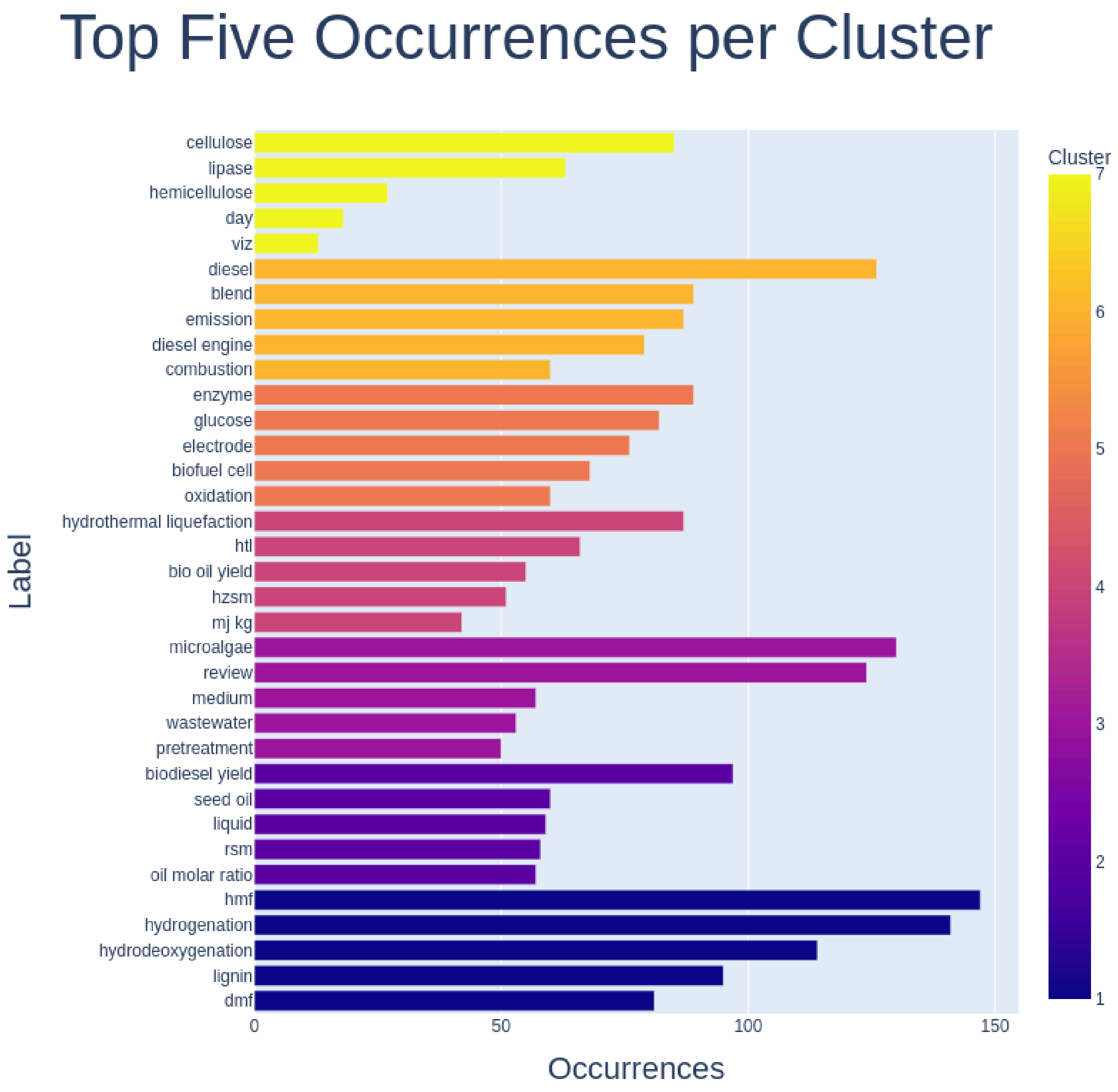

**Figure 6.** *Top five nodes per cluster from VOS analysis on titles and abstracts retrieved from the Scopus database*

Regarding the nodes of Cluster 1, shown in Figure 6, second-generation biofuels that use lignocelluloses or celluloses are outstanding alternatives to fossil fuels. Besides, lignocellulosic biomass and carbohydrates are the preferred green, sustainable, and inedible raw materials to prepare various biofuels and valuable chemicals. In particular, furan-based fuels such as 2,5-dimethylfuran (DMF) and 5-hydroxymethylfurfural (HMF) provide a higher energy density than ethanol. DMF is insoluble in water. HMF is a critical intermediate for the DMF synthesis process. DMF is a promising fuel for compression-ignition and spark-ignition engines. These species can improve engine performance, emission, and combustion characteristics compared to other liquid biofuels without

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modifying the engine structure. Thus, the high energy density, low freezing point, high octane number, high boiling point, high combustion quality, and low pollution emissions make DMF a suitable alternative for commercial gasoline and diesel[34]. Besides being potential biofuels, DMF and HMF are known as intermediates to synthesize other biomaterials and pharmaceuticals[35][36][37][38][39][40], which add value to these molecules.

In turn, regarding the nodes of Cluster 2, the growing concern with the sustainability of several first-generation biofuels is the critical concern of several works that seek the production of biodiesel from non-food crops. This fuel is called second-generation biodiesel, and its main positive points are the consumption of residual oils, the use of abandoned land, and the independence of food crops. Still, the global biofuel production market has not expanded considerably. Among biofuels, biodiesel has the most significant potential for use as an alternative, biodegradable, renewable, and environmentally friendly fuel. Despite this, production optimization is a vital issue for increasing the scope of this biofuel. For this, the use of residual oils, the selection of inedible oilseed species with high oil yield, and the optimization of processes are fundamental studies[41]. Among the optimization techniques, the response surface methodology stands out due to its advantages, such as the determination of the independent variables' magnitudes, the ability to model the system mathematically, as well as the time savings, and cost reduction due to the smallest number of necessary experiments for the construction of the response surface[42][43][44][45][46][47][48][49][50][51][52][53][54].

As for the nodes of Cluster 3, different wastewater sources such as municipal, agricultural and industrial contain significant amounts of organic and inorganic contaminant nutrients that are released into water bodies without proper treatment, resulting in eutrophication. The main reason for the waste above is the absence of efficient and economical methods for wastewater treatment. However, wastewater is perfect for microalgae growth. These are single-cell photosynthetic organisms capable of growing in wastewater and even sewage. Thus, wastewater treatment with microalgae is advantageous, as it decreases the biochemical oxygen demand (BOD), the chemical oxygen demand (COD), and removes inorganic nutrients (nitrates and phosphates) from wastewater, in addition to sequestering carbon dioxide via biofixation of inorganic carbon from the atmosphere. Despite the incredible versatility of microalgae, wastewater has different compositions and needs to be treated beforehand[55]. Thus, it is often necessary to adjust nutrients and other factors such as temperature, pH, salinity, light intensity, and duration of the microalgae growth process. Another crucial issue is the selection of microalgae species[56][57][58][59][60][61][62][63]. Finally, the microalgae-mediated wastewater treatment can directly produce biofuel (bioelectricity and biohydrogen), besides lipid-rich biomass, essential for biodiesel production[64][65][66].

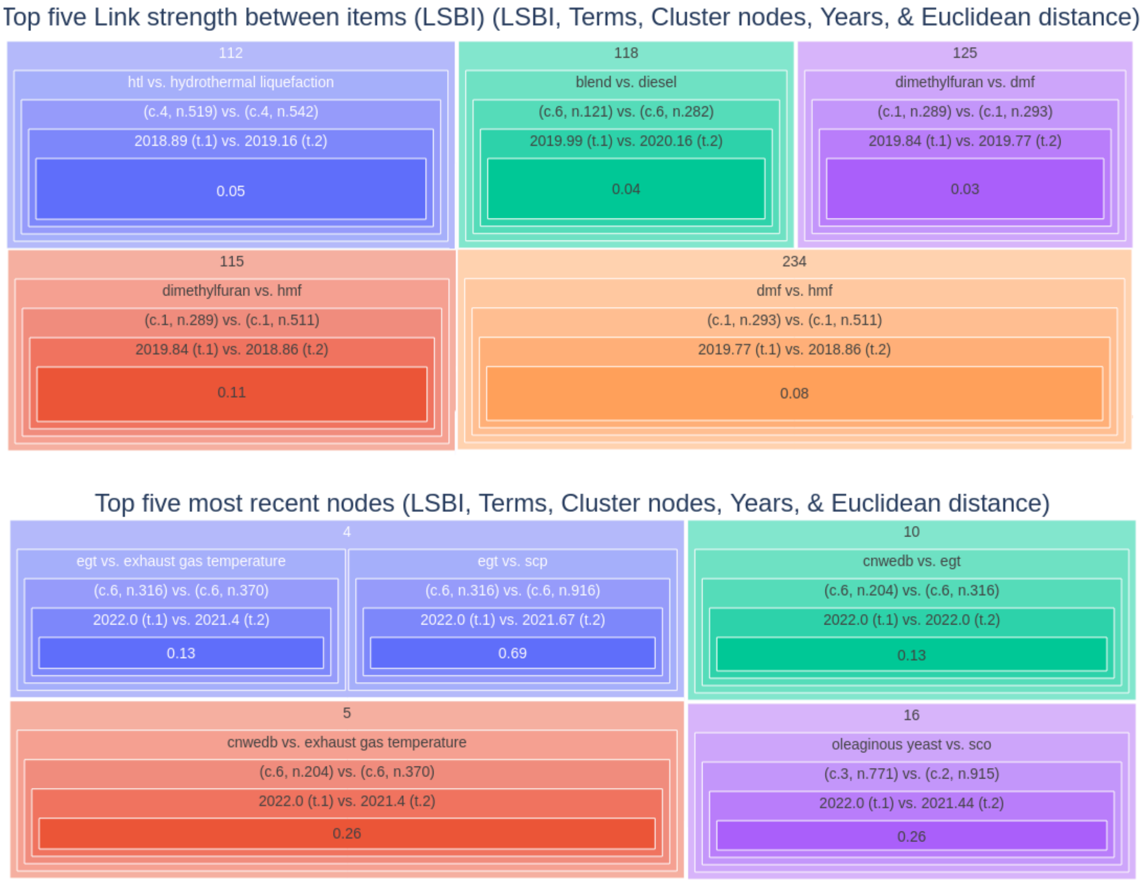
Concerning Cluster 4, biomass conversion methods mainly consist of biochemical methods such as fermentation and thermochemical methods, which include combustion, pyrolysis, gasification, and liquefaction. The latter, thermochemical liquefaction, is an efficient and promising way to convert biomass into solid waste, liquid or bio-crude fuel, and gas. Hydrothermal liquefaction (HTL) is the thermochemical process that treats wet biomass at temperatures between 250 and 350 °C and pressures between 5 and 15 Mpa. HTL is done in the presence of a solvent, which can be water or alcohol, with or without a catalyst. The catalysts greatly influence the yield and quality of the bio-crude obtained via the HTL process. Various acid or alkaline catalysts can be used. However, they cause corrosion of liquefaction equipment and require additional steps for separation/purification increasing production costs. Thus, replacing conventional catalysts with heterogeneous ecological catalysts is pivotal in improving bio-crude yield and quality in biomass liquefaction[67]. The heterogeneous Ni/HZSM-5 catalyst is hydrothermally stable, improving the pyrolysis bio-oil. Furthermore, the Ni/HZSM-5 catalyst can be reused as they are heterogeneous solids separated and recovered from the reaction products. In addition, they are disposed of safely[68][69][70][71][72][73][74].

Regarding Cluster 5, obtaining energy from renewable resources is one of humanity's main goals, and one option for this goal is enzymatic biofuel cells. These devices can convert energy derived from biofuels into electrical energy via the catalytic action of oxidoreductase enzymes. This known technology has been neglected due to its inherent difficulties besides the easier and faster development of metallic electrocatalysts for fuel cells. Protein immobilization and stabilization reached the necessary advance only at the end of the 20th Century. Due to the incomplete oxidation of biofuels, enzymatic biofuel cells suffer from low energy density. For instance, glucose enzymatic biofuel cells can generate 2 electrons. However, 24 electrons can be released from glucose, showing that there is still much ground for increasing the efficiency of these devices[75]. The use of enzyme cascades is an alternative to maintaining the high energy densities of biofuel cells and increasing energy density. Enzyme cascades can mimic the metabolic pathways of enzymes to completely oxidize substrates such as ethanol and increase power density by almost ten times compared to a single enzyme ethanol biofuel cell[76][77][78][79][80][81][82][83][84][85][86].

Regarding Cluster 6, the transport sector is the leading consumer of diesel, producing massive emissions in internal combustion (IC) diesel engines. This environmental impact can be minimized or eliminated using blends of diesel with biodiesel or biodiesel alone. Biodiesel is the safest alternative automotive fuel with low particulate and hydrocarbon emissions. However, biodiesel in engines presents challenges, mainly due to this biofuel's low volatility and high viscosity, characteristics restricting fuel spraying, and good air-fuel mixture. Biodiesel-diesel blends need additional studies for their use, and the lack of knowledge of the performance of biodiesel-diesel in diesel engines is the reason for the lower use of the blend of these fuels. One of the limitations of biodiesel as a fuel for IC engines is its high viscosity which increases NOx emissions. The diesel engine design must be modified to use biodiesel without additives, allowing for efficient self-ignition and fuel lubricity, which can be achieved using oxygenated compounds such as ethanol. Several studies discuss diesel-alcohol and diesel-biodiesel-alcohol mixtures. Although biodiesel blend in diesel engines has many advantages, the main drawback is small oxidative steadiness, generating peroxides and hydroperoxides and monomeric, oligomeric, and short-chain compounds produced via rearrangement, fission, and dimerization reactions[87]. Although the IC engine guarantees low fuel consumption and low carbon dioxide emissions, this engine is a source of particulate matter and nitrogen oxide emissions, with unfavorable effects on human health and the environment[88][89][90][91][92][93][94][95][96][97][98][99][100][101]. Therefore, studies on fuel mixtures and new engine designs are essential for expanding the use of biofuels.

Regarding Cluster 7, a tendency in the fast evolution of biomass decomposition techniques uses cellulase enzymes from multiple domains of microorganisms. The enzymatic decomposition of cellulose depends mainly on glycosidic hydrolases and oxidative enzymes. Several organisms produce cocktails of "free enzymes" that synergistically degrade biomass. Enzymatic action involving three-dimensional arrangements of proteins and the chemical biology of enzymes are emerging fields. However, the physicochemical persistence of cellulose and chitin limits fast and economic degradation. Most commercial enzymes are of fungal origin. Bacterial cellulosomes substantially increase the hydrolytic activity of fungal cellulase. Methods for producing cellulosic liquid biofuels by enzymatic hydrolysis have been developed since the end of the 20th Century[75][102]. Advances such as Genetic Engineering have opened new horizons for this field of study, and several pieces of research have been developed[103][104][105][106][107][108][109][110].

The Treemaps in Figure 7 show the five main pairs of links extracted from the network database generated by VOSviewer. Treemaps bring, from outside to inside, information about Terms, Link Strength Between Items (LSBI), years, clusters, and Euclidean Distances (E.D.), respectively. More specifically, the top Treemap is sorted by the highest LSBI values, while the bottom one follows a classification by the most recent years of the respective nodes. These Treemaps, as well as the results shown in Table 1, are the direct result of the software developed especially for this work, which allows associating the numerical information provided in the Network file with the labels, years, and strength of the links of the files generated by VOSviewer.


Top five Link strength between items (LSBI) (LSBI, Terms, Cluster nodes, Years, & Euclidean distance)

Top five most recent nodes (LSBI, Terms, Cluster nodes, Years, & Euclidean distance)

**Figure 7.** *Top five link strength between terms and top five most recent linked terms from VOS analysis on titles and abstracts retrieved from the Scopus database*

| **Top five link strength between terms** | | | |
|---|---|---|---|
| **Terms (t.1 vs. t.2)** | **LSBI ↓** | **Years (t.1 vs. t.2)** | **E.D.** |
| 1. *dmf vs. hmf* | *234* | *2019.77 (t.1) vs. 2018.86 (t.2)* | *0.08* |
| 1. dimethylfuran vs. dmf | 125 | 2019.84 (t.1) vs. 2019.77 (t.2) | 0.03 |
| 1. *blend vs. diesel* | *118* | *2019.99 (t.1) vs. 2020.16 (t.2)* | *0.04* |
| 1. *dimethylfuran vs. hmf* | *115* | *2019.84 (t.1) vs. 2018.86 (t.2)* | *0.11* |
| 1. htl vs. hydrothermal liquefaction | 112 | 2018.89 (t.1) vs. 2019.16 (t.2) | 0.05 |
| | | | |
| **Top five most recent linked terms** | | | |
| **Terms (t.1 vs. t.2)** | **LSBI** | **Years (t.1 vs. t.2) ↓** | **E.D.** |
| 1. *cnwedb vs. egt* | *10* | *2022.0 (t.1) vs. 2022.0 (t.2)* | *0.13* |
| 1. egt vs. scp | 4 | 2022.0 (t.1) vs. 2021.67 (t.2) | 0.69 |
| 1. *oleaginous yeast vs. sco* | *16* | *2022.0 (t.1) vs. 2021.44 (t.2)* | *0.26* |
| 1. egt vs. exhaust gas temperature | 4 | 2022.0 (t.1) vs. 2021.4 (t.2) | 0.13 |
| 1. *cnwedb vs. exhaust gas temperature* | *5* | *2022.0 (t.1) vs. 2021.4 (t.2)* | *0.26* |

**Table 1.** *Main information from treemaps containing the top five LSBI and top five most recent linked terms*

Regarding the highest values of Link Strength Between Items or Terms (LSBI), the 2,5-Dimethylfuran (DMF) vs. 5-Hydroxymethylfurfural (HMF) appears twice in Table 1 (see lines 1 and 4), with LSBI values equal to 234 and 115, respectively. The observed repetition is that the terms appear written in abbreviated and complete forms. Something similar occurs in lines 2 and 5, which have the repeated dimethylfuran vs. dmf and htl vs. hydrothermal liquefaction (HLT). Thus, only two sets of pairs should be considered, which are (i) 2,5-Dimethylfuran (DMF) vs. 5-Hydroxymethylfurfural (HMF) and (ii) blend vs. diesel, both highlighted in blue and italics. Once again, as discussed above, it is clear the great importance of HMF & DMF as alternative fuels, which can add extra value due to their ability to be used as precursors for several other chemicals. In addition, the other duo, Blend & Diesel, has relevance due to the continuous process of researching innovations and improvements in IC engines, responsible for most of the land transport performed by humanity. These researches are fundamental for reducing the anthropocentric impact of particulates and carbon dioxide emissions that are responsible for several environmental imbalances.

Regarding the most recent connected terms, shown at the bottom of Table 1, the $CeO_2$ nanoparticles-dispersed water–diesel–biodiesel fuel blend (CNWEDB) vs. Temperature of the engine exhaust (EGT) appears twice in Table 1, lines 6 and 10, and have LSBI values equal to 10 and 5, respectively. Something similar occurs in line 9, which has the repeated terms Temperature of the engine exhaust (EGT) vs. Temperature of the engine exhaust (EGT). Thus, only three sets of pairs could be considered. However, among the three possible candidates, only two presented higher LSBI values, which are (iii) $CeO_2$ nanoparticles-dispersed water–diesel–biodiesel fuel blend (CNWEDB) vs. Temperature of the engine exhaust (EGT) and (iv) oleaginous yeast vs. Single cell oils (SCO). Their LSBI values are equal to 10 and 16, respectively. Among these same two pairs, the first has values from more recent years [2022.0 (t.1) vs. 2022.0 (t.2)] than the year values presented by the second [2022.0 (t.1) vs. 2021.44 (t.2)].

Regarding the first pair of more modern terms, there is scientific evidence that the oxygen present in biodiesel decreases the produced carbon monoxide and the hydrocarbon emissions of the IC engine. On the other hand, as a significant disadvantage, the higher oxygen content of biodiesel leads to higher concentrations of NOx. Compared to pure biodiesel, NOx emissions can be reduced by using water-in-biodiesel fuel emulsions. In addition, some experimental studies investigated the use of $CeO_2$ nanoparticles as an additive in diesel-biodiesel fuel mixtures and their impact on the thermal and environmental behavior of the CI diesel engine. HC releases are reduced by fifty percent using CeO2 trapped on amide-functionalized multiwall carbon nanotubes (MWCNT) nanocatalysts dissipated in the B20 mixture[111]. The engine running on this mixture also produced lower CO emissions than the base fuel. More recently, it has been proven that the presence of CNWEDB increases the brake thermal efficiency of the engine by almost eight percent in comparison to diesel. Also, the heat losses were observed at eighty percent engine load for CNWEDB, indicating a minimum better conversion of fuel energy to useful work[112].

Regarding the second pair of more recent terms, yeasts are microbial agents for the efficient production of free alkanes, fatty acids, and fatty alcohols[113]. For instance, the yeasts *Rhodotorula glutinis* and *Rhodosporidium toruloides* can store more than eighty percent of lipids in their organisms[114]. Single-cell oils (SCOs) are microbial oils derived from algae, bacteria, fungi, and oleaginous yeasts[115]. Oleaginous yeasts are able to use various inexpensive carbon sources, such as agro-industrial fritters such as corn husk, paper mill waste, sugarcane molasses, wheat bran, and wheat straw, making single-cell oils production commercially viable and sustainable[116]. Thus, a series of tailings can be used, reducing the environmental impact of several monocultures and even untreated effluents[117][118][119][120].

Therefore, this work establishes that the use of yeasts for the production of fats later transformed into biodiesel and systems based on cerium oxide nanoparticles are critical themes for the scientific and technological developments related to the energetic use of renewable resources.

## Conclusions

This work established a new data manipulation procedure assisted by the Visualization of Similarities Method and Python. The analysis of more than a thousand papers on biofuels and nanocatalysts by this process showed the existence of two sets of pairs of terms, classified according to their LSBIs and their years of publication. The analysis based on the LSBI values demonstrates the great importance of HMF & DMF as alternative fuels. Research on Blend & Diesel is fundamental for reducing the anthropocentric impact of particulates and carbon dioxide emissions responsible for several environmental imbalances. In turn, the analysis based on the modernity of the sets of pairs of terms showed that using microorganisms to prepare oils and cerium oxide nanoparticles to increase the efficiency of burning fuel mixtures are hot topics that still can be extensively explored. Thus, the concern with energy efficiency and environmental preservation is critical for the scientific and technological developments related to the energetic use of renewable resources.

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