Bioeconomy in Brazil and the world

SCIENTIFIC PRODUCTION OVERVIEW

In this issue:

This is the first edition of the Bioeconomy Thematic Report which aims to analyze the panorama of bioeconomy scientific production in in Brazil and the world.

Over the last decade, the term "bioeconomy" has appeared with increasing frequency in both scientific publications and national strategies/plans in the drive towards a sustainable low-carbon economy. However, searching for the term on scientific databases fails to capture its entire scope of activity (Fig. 1) as it is a recent and quite transversal theme. This report considers the following definition of the term:

*"The **bioeconomy** comprises all of the economic activity derived from bioprocesses and bioproducts contributing to efficient solutions in the use of biological resources – pertaining to challenges in food, chemicals, materials, energy production, health, environmental services and environmental protection - that promote the transition to a new model of sustainable development and social well-being" (CGEE, 2020)."*

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MINISTRY OF
**SCIENCE, TECHNOLOGY
AND INNOVATIONS**

Despite a marked increase in the number of publications (Figure 1), scientific production remains low. Therefore, a methodology was formulated based on the semantic similarity between publications extracted from the Web of Science (WoS) database to access a representative sample of bioeconomy-related publications, considering abstracts, titles and the set of keywords provided by the authors/journals.
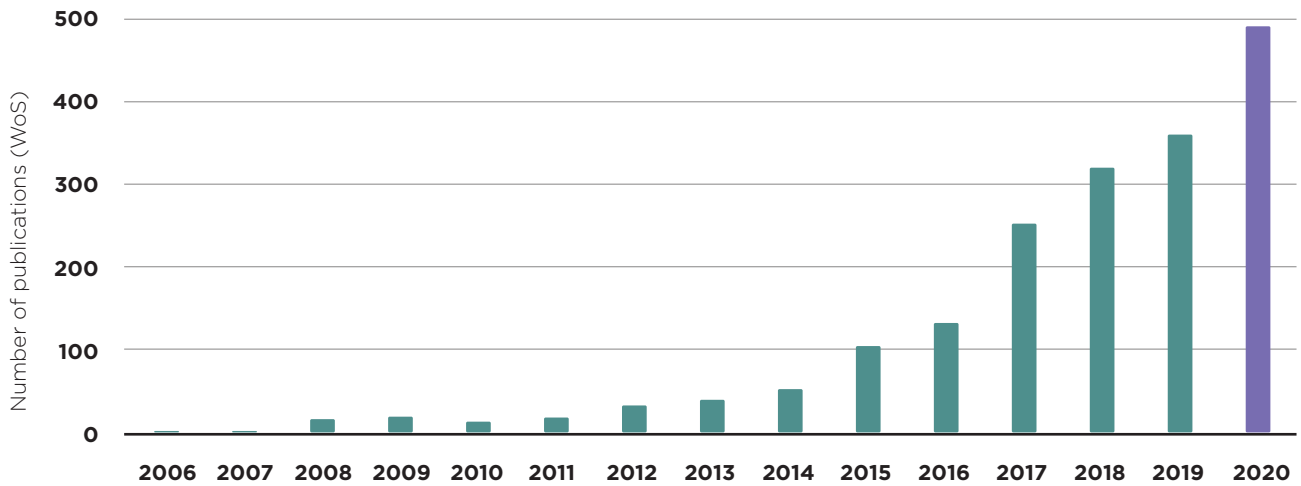
Figure 1: Evolution of bioeconomy-related publications (2006 - 2020).

Snowball Methodology

Identification of trios of keywords in decreasing order of co-occurence

Exclusion of records not directly connected to the data of the first consultation

NETWORK 1:

1,675 publications

"bioeconomy"

New query with

7 keywords

in 35 different triple combinations

Network 2

20,361 publications "bioeconomy" + 35 keyword combinations

Network 3

(final)

4,640 publications

Calculation: modularity, eigenvector centrality and average clustering coefficient

Export data to iN Browser and Excel for interpretation

**Biomass
Biofuel
Bioenergy
Biorefinery
Sustainability
Innovation
Circular Economy**

Figure 2: Snowball sampling protocol.

The network of bioeconomy-related scientific publications was analyzed using snowball sampling. This method generates search expressions that, in turn, enable the identification of scientific publications relating to a new comprehensive expression. The protocol is detailed in Fig. 2.
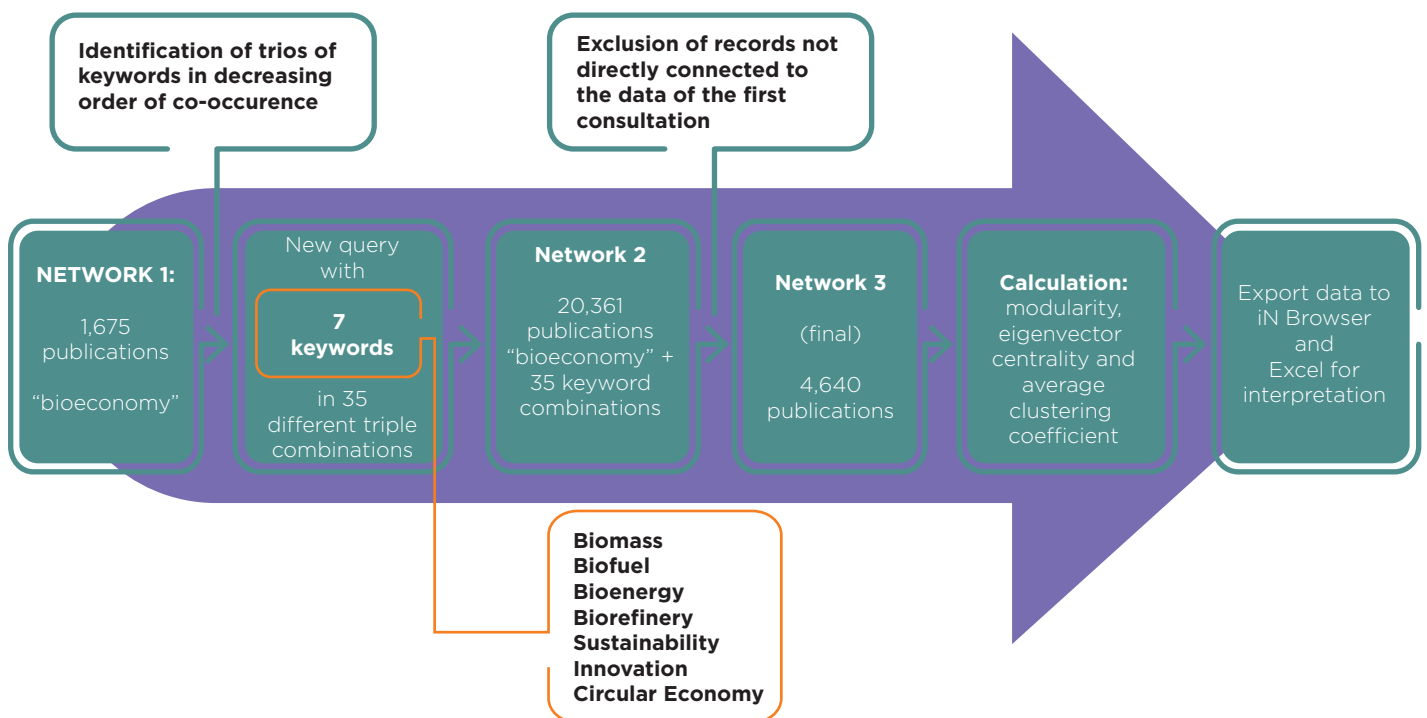
1. Overview

Figure 3 shows the semantic similarity network of the 4640 publications constructed following execution of the snowball protocol, colored according to the different clusters formed. Figure 4 presents the keyword cloud (authors and journals) generated for the entire network. Analysis of the most cited keywords points out some relevant indicators. First, there is the word **biomass**, which is in fact the basis of the bioeconomy, relating to the proposal of new bio-based raw materials for the production of energy and bioproducts.

Figure 3: Papers Network (colored by modularity class).

However, the subsequent two words - **biofuels** and **bioenergy** - illustrate energy products, which are clearly just a segment of the bioeconomy. Nevertheless, energy products comprise a large share of what has been considered the "bioeconomy" by researchers. This result reflects the main use of biomass in a trajectory towards a low-carbon economy. The fourth and fifth most cited words, however, point to another direction, the identification of new biomass applications in addition to energy production. The words **bioeconomy** and **biorefinery** illustrate this trend. It is also noteworthy that **sustainability** and **innovation** are among the 10 most cited terms, concepts strictly linked to the aforementioned bioeconomy definition.

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1ª	biomass	1181
2ª	biofuel	801
3ª	bioenergy	526
4ª	bioeconomy	435
5ª	biorefinery	376
6ª	anaerobic-digestion	149
7ª	sustainability	144
8ª	waste	141
9ª	biogas	138
10ª	innovation	128

Figure 4: Keyword cloud generated for the entire network.

Figure 5 is an ordinal representation of the 15 countries with the most bioeconomy-related publications according to the network. The graph also indicates the proportion of publications that were in collaboration with other countries. On average, 48% of these publications involved some degree of partnership with other countries. The Netherlands and France stand out with 70.5% and 60.1% cooperation, respectively, while Brazil was ranked 11 (41.9%).

Figure 5: Top 15 countries with the highest number of bioeconomy-related publications in the semantic similarity network.

2. Thematic Clusters

Thematic clusters were selected from the generated network based on the degree of semantic similarity[1] between publications.

The 25 largest clusters were considered, of which the 15 most cohesive were subsequently selected and reported herein.

Figure 6 illustrates the clusters selected and Table I provides the corresponding theme classification.

Tabela 1: Cluster theme classification

	Cluster Theme
1	forest biomass
2	biogas
3	grass
4	valorization of waste and coproducts
5	algae and Lipids
6	lignin
7	biochar
8	palm oil
9	straw
10	microalgae and wastewater treatment
11	hydrogen
12	torrefaction
13	*Miscanthus x Giganteus*
14	circular economy
15	corn biomass

Figure 6: Visualization of the top 15 clusters in a 3D data space.

The 15 thematic clusters selected are presented in the following section. The following data is provided for each cluster: description, the 5 countries with the most publications (WoS database) and the corresponding word cloud. The decision was made to analyze all of the words in each publication to ensure that each word cloud generated reflected the central theme of the cluster[2]: the: title, abstract and keywords.

2.1. Cluster 1 – Forest Biomass

This cluster focused on analyzing the production and use of forest biomass (residual or non-residual) for power generation and product replacement (Fig. 7).

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1 Semantic similarity analysis takes into account publications' title, abstract and keywords.

2 The word cloud tests generated very similar images between the clusters, having the repetition of words like biofuel, bioenergy and bioeconomy as the most frequent ones. The inclusion of the words in the title and abstract emphasized the themes addressed in the clusters, improving the analysis.

The theme of forest biomass is treated in several ways including production methods; transformation processes; technical and economic feasibility analysis; life cycle analysis; land-use implications; public policies, and ecosystem analysis.

Figure 7: Cluster 1 word cloud.

Figure 8: Top 5 publishing countries in cluster 1.

2.2. Cluster 2 – Biogas

Cluster 2 gathers articles regarding the production, evaluation and use of biogas. The central, and most condensed, part of the cluster represents reviews together with articles about biogas assessments, such as the advantages/disadvantages for different countries or regions, production potential, and energy generation potential. In the peripheral regions of the cluster, it is possible to identify some specific characteristics, such as the production of biogas from composting, the anaerobic digestion process, technical viability studies and life cycle analyses (Fig. 9).

Figure 9: Cluster 2 word cloud.
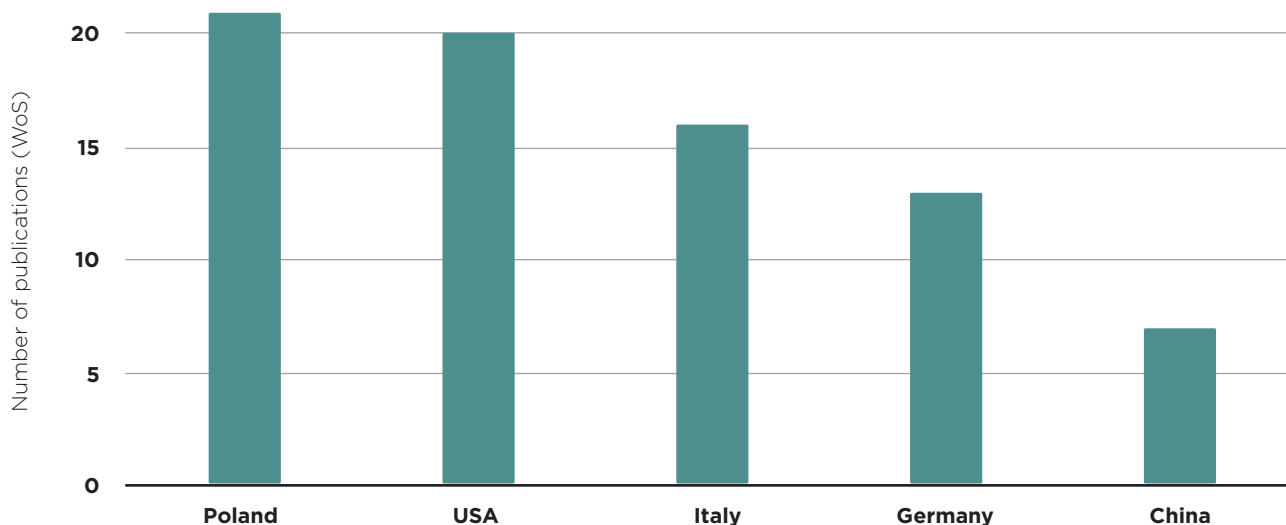
Figure 10: Top 5 publishing countries in cluster 2.

2.3. Cluster 3 – Grass

Cluster 3 focuses on energy crops, more specifically grasses, with emphasis on the Miscanthus and Arudo genera. Divided into 2 main nuclei, it has nodes scattered throughout its neighborhood. The lower nucleus relates to a large body of Italy-based research into grasses, especially of the two aforementioned genera. The upper nucleus encompasses other crops, however, the research goals are quite similar. Bioenergy is the primary focus, but other aspects are also addressed, including gas emissions, productivity and soil dynamics (Fig. 11).

Figure 11: Cluster 3 word cloud.

Figure 12: Top 5 publishing countries in cluster 3.

2.4. Cluster 4 – Valorization of waste and coproducts

Cluster 4 mainly deals with the recovery of waste and co-products. At its core, there is a concentration of articles focused on the use of sewage sludge for energy production. However, there are groups of nodes in the peripheral regions dealing with the recovery of other residues and co-products, especially glycerol from biodiesel production and lignocellulosic residues (Fig. 13).

Figure 13: Cluster 4 word cloud.
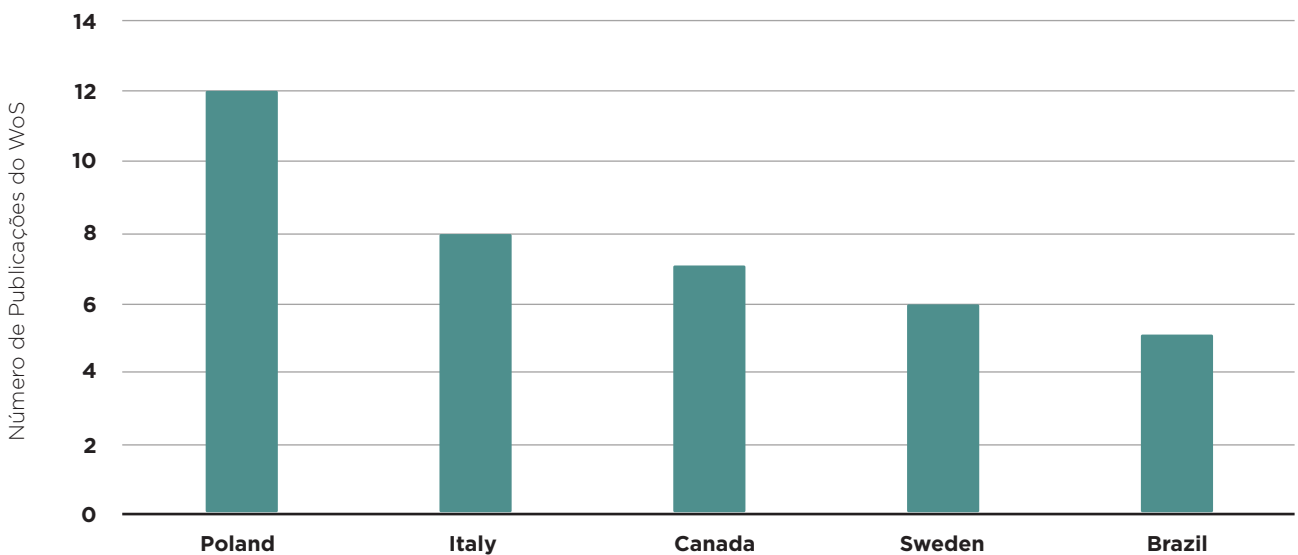
Figure 14: Top 5 publishing countries in cluster 4.

2.5. Cluster 5 – Algae and lipids

Cluster 5 is larger but more dispersed than those previously mentioned. Most publications are concerned with topics relating to the use of algae for the production of bioenergy and biofuels or lipid extraction processes from algae and microalgae (Fig. 15).

Figure 15: Cluster 5 word cloud.

Figure 16: Top 5 countries in cluster 5.

2.6. Cluster 6 – Lignin

The main core of cluster 6 involves research into alternative lignin applications. There is a broad range of topics, from the production of paper, renewable chemicals fuels, and use in biorefineries, to the physical, chemical, and biological properties of the material. We can also observe related themes such as cellulose processing in peripheral regions of the cluster (Fig. 17).

Figure 17: Cluster 6 word cloud.
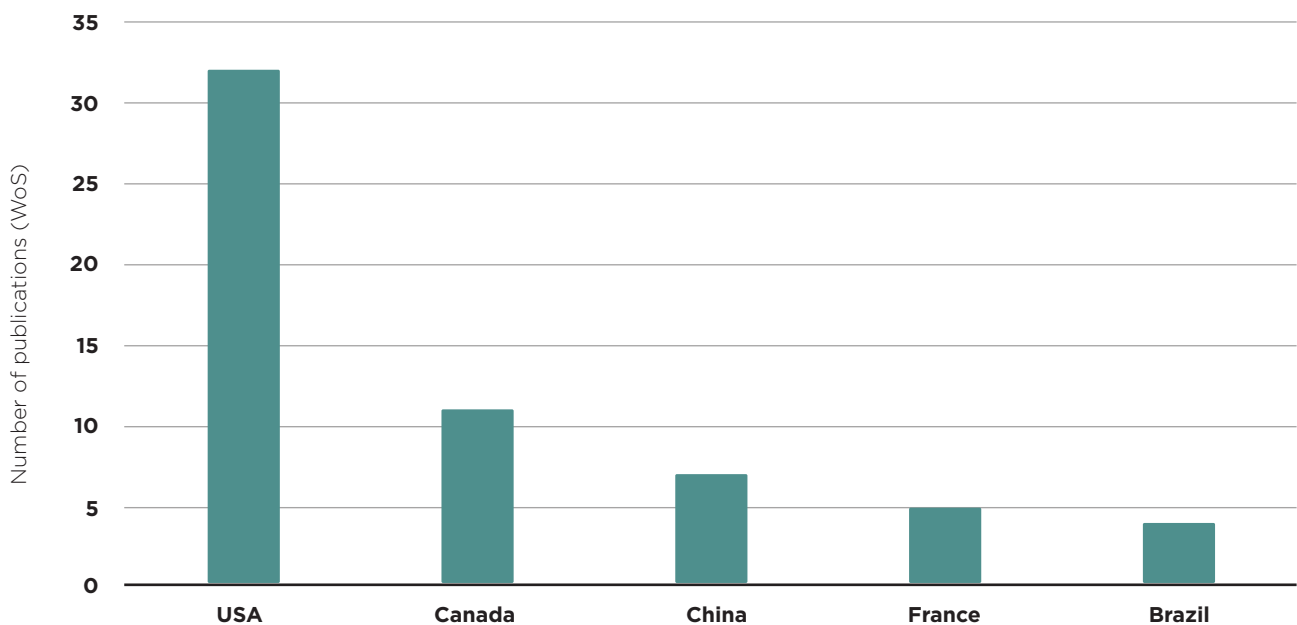
Figure 18: Top 5 publishing countries in cluster 6.

2.7. Cluster 7 – Biochar

Cluster 7 stands out for being highly dense. All of its nodes are concentrated in the same space within the network, representing the same theme - biochar, a carbon-rich material used as a soil corrector to improve its quality. The cluster highlights topics including different biochar production methods: pyrolysis, gasification, and hydrothermal conversion; among others such as environmental and economic impacts, regulatory aspects and risk analysis (Fig. 19).

Figure 19: Cluster 7 word cloud.

Figure 20: Top 5 publishing countries in cluster 7.

2.8. Cluster 8 – Palm Oil

With palm oil as its principal theme, Cluster 8 is relatively dense, consisting of reviews, technical and economic analyses, and life cycle analyses. In this cluster, Malaysia stands out as the country with the highest number of publications (Fig. 22).

Figure 21: Cluster 8 word cloud.
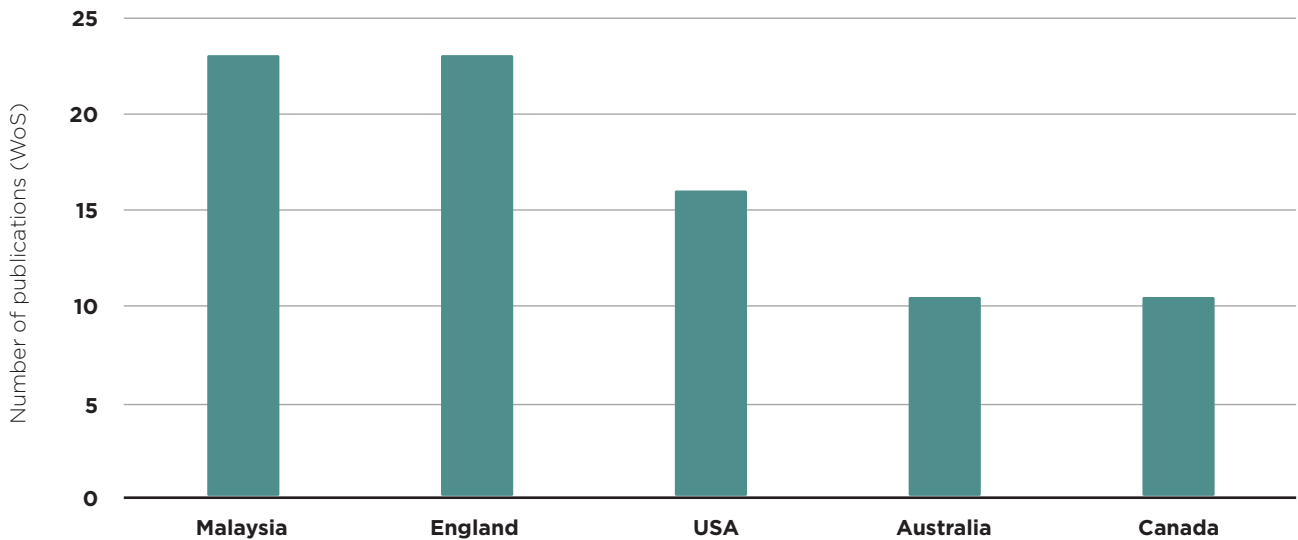
Figure 22: Top 5 publishing countries in cluster 8.

2.9. Cluster 9 – Straw

This cluster mainly deals with the use of straw from various agricultural products such as sugar cane, corn, and wheat in the generation of energy and transformation into bioproducts. In addition to reports concerning straw applications, there is also a strong presence of themes relating to the availability of this biomass and soil quality assessments after straw harvesting. It is also noteworthy that Brazil publishes the most within this topic, particularly relating to sugarcane straw applications (Fig. 23).

Figure 23: Cluster 9 word cloud 9.

Figure 24: Top 5 publishing countries in cluster 9.

2.10. Cluster 10 – Microalgae and wastewater treatment

Cluster 10 is very cohesive, focusing on the use of microalgae in the treatment of effluents and subsequent transformation into energy and bioproducts. This cluster is very close to cluster 5 (algae and lipids), but the specificity of the topic in question was sufficient to generate a new modularity class. India published the most on this subject, while Brazil ranked number 4 (Fig. 26).

Figure 25: Cluster 10 word cloud.

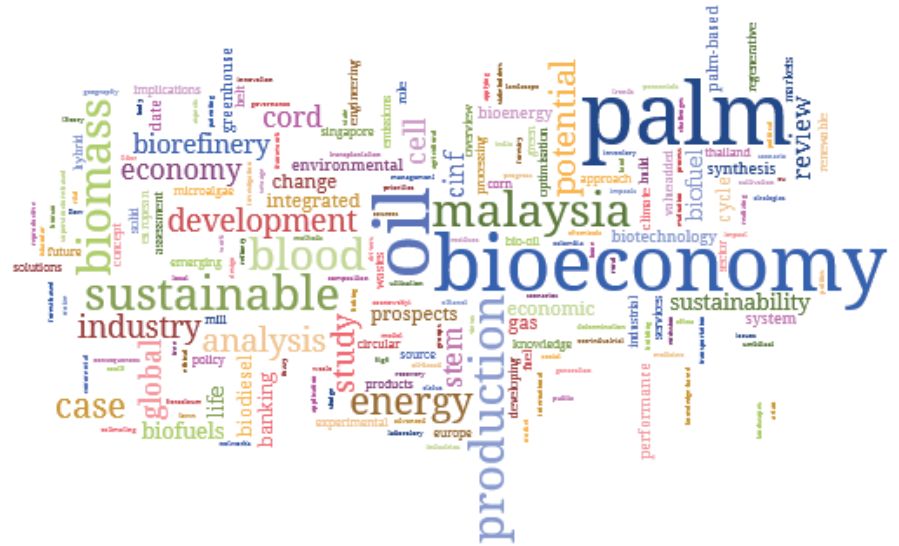**Figure 26:** Top 5 publishing countries in cluster 10.

2.11. Cluster 11 – Hydrogen

This cluster focuses on hydrogen production, predominantly by biomass gasification, but also by other processes such as anaerobic digestion and fermentation. In addition to technical publications focused on the hydrogen generation process, many review articles and life cycle analyses were also noted (Fig. 27).
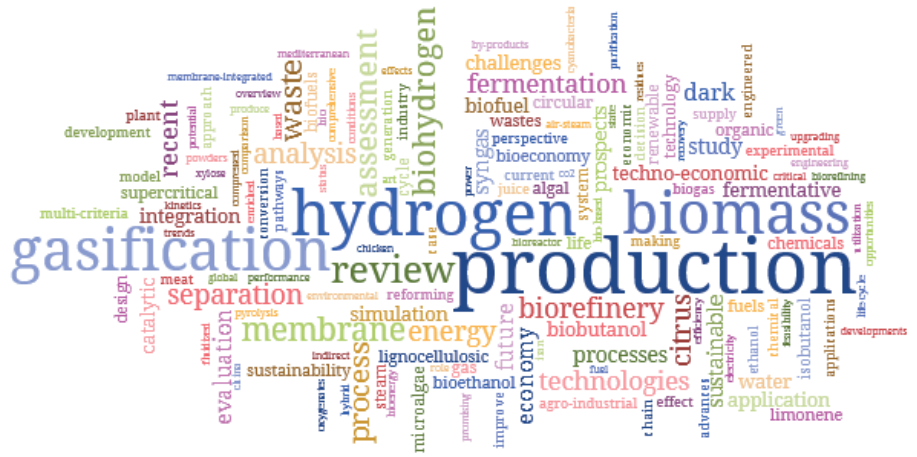
Figure 27: Cluster 11 word cloud.
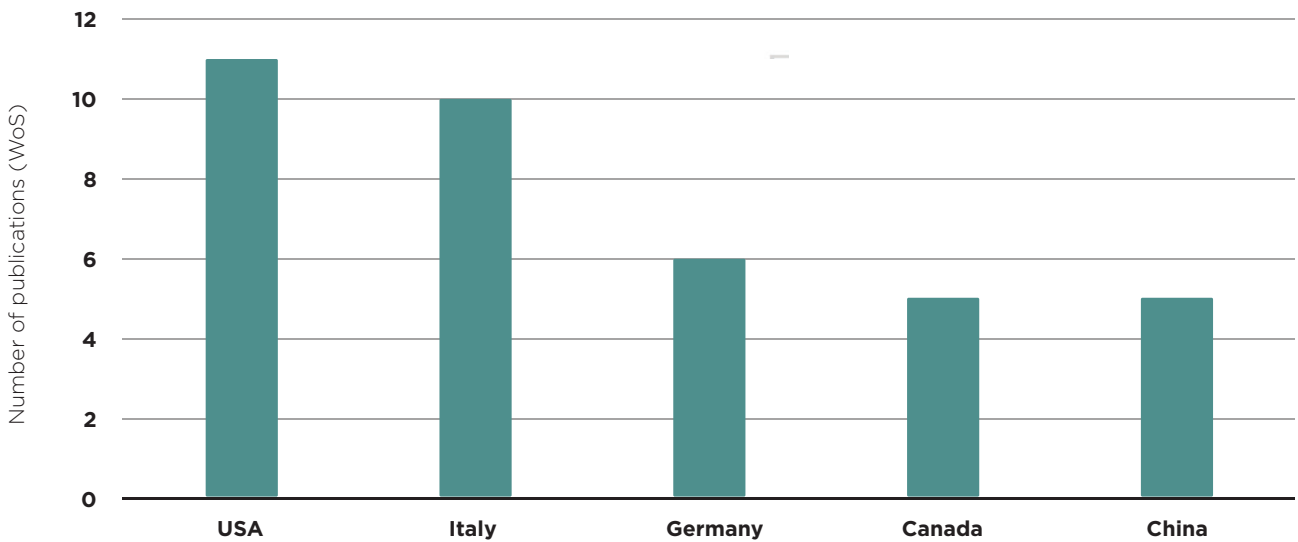
Figure 28: Top 5 publishing countries in cluster 11.

2.12. Cluster 12 – Torrefaction

The central theme of cluster 12 is the biomass torrefaction, a thermochemical process that maintains about 75-95% of the energy content. Thus, this cluster gathers publications dealing with this topic, focusing on energy use, the preparation of biomass for gasification processes, and pellet production (Fig. 29). The strong participation of the USA stands out, as does Brazil, ranked number 5 in the countries that published the most within this topic.

Figure 29: Cluster 12 word cloud.

Figure 30: Top 5 publishing countries in cluster 12.

2.13. Cluster 13 – *Miscanthus x Giganteus*

The main theme addressed in this cluster is the large carbon capture capacity of African and Eurasian plants. Publications within this cluster mainly relate to the production of bioenergy/biofuels from *Miscanthus x giganteus* and productivity evaluations (Fig. 31).

Figure 31: Cluster 13 word cloud.

Figure 32: Top 5 publishing countries in cluster 13.

2.14. Cluster 14 – Circular economy

Cluster 14 is strongly characterized by the circular economy theme and what is termed the "circular bioeconomy". Within this theme, the publications mainly consider new business models for bioproducts. It is also worth mentioning a subgroup within the cluster focused on the circular economy in the Baltic countries (Fig. 33).

Figure 33: Cluster 14 word cloud.

Figure 34: Top 5 publishing countries in cluster 14.

2.15. Cluster 15 – Corn biomass

In this cluster, there is an emphasis on research into cellulosic ethanol with corn biomass, such as **corn stover** - a set of leaves, stems and corncobs. Figure 36 clearly shows that the United States is the leader in this field of research which is not surprising given the considerable interest the country has in the subject. Several country-specific studies can be found, for example, the life cycle analysis of maize grain and maize straw in the USA. Brazil features in the top 5 countries of this cluster (Fig. 36), albeit with a considerably lower number of publications.
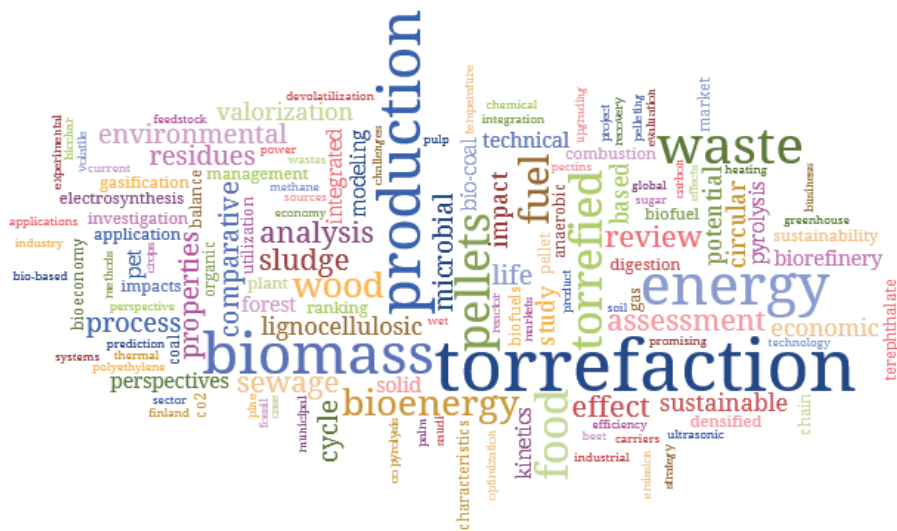

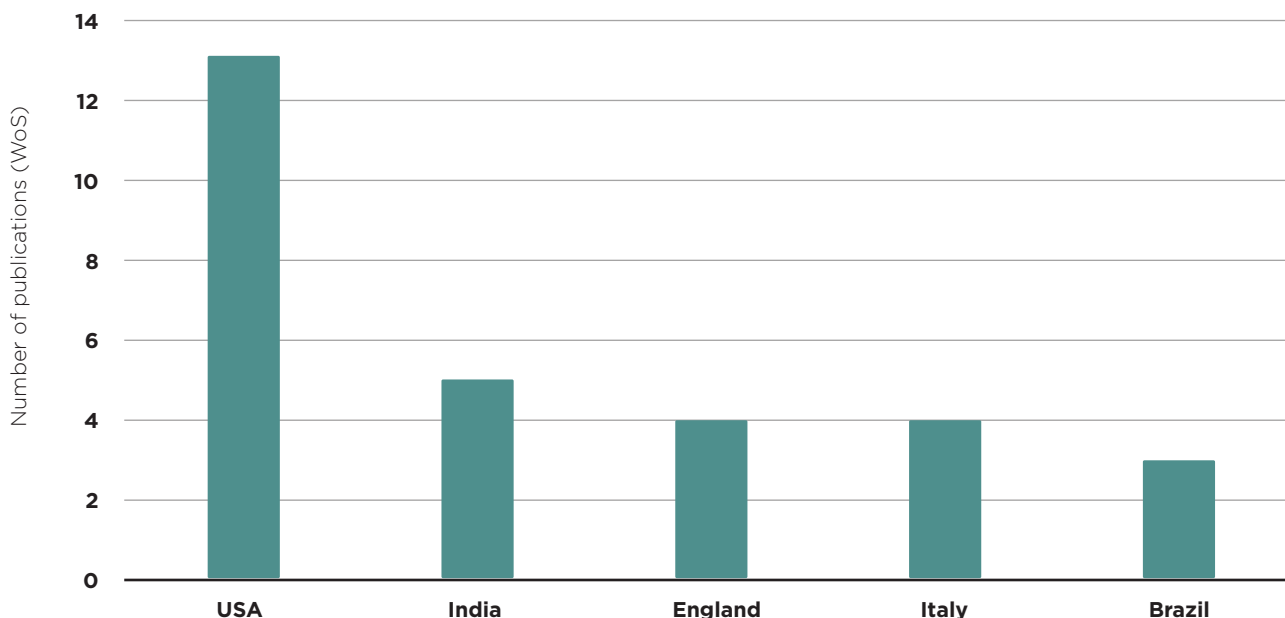**Figure 35:** Cluster 15 word cloud.

Figure 36: Top 5 publishing countries in cluster 15.

2.16. Considerations for cluster analysis

Cluster analysis enabled the identification of several segments of the bioeconomy, chiefly those associated with the production and processing of renewable raw materials (RRM). Of the 15 clusters examined, 9 were directly associated with an RRM, while the other 6 related to the topics of bioproducts, processing and the circular economy. This result reinforces the idea that the main dimension of the bioeconomy relates to the substitution of fossil raw materials with renewable ones.

It is important to mention that the network characterization herein was non-exhaustive, with the 15 clusters representing 42% of the network (a total of 1947 articles). Several themes also present in the network, such as biodiesel (239 articles), sugar cane (437 articles) and bioplastics (50 articles), did not form semantic similarity clusters large enough to warrant selection for the characterization process.

Thus, to deepen the discussion of the generated network, the 5 countries that published the most in the bioeconomy field - the USA, Germany, Italy, China, and England - were further analyzed together with Brazil. Analysis by country is important in the context of the bioeconomy due to the strong influence that regional characteristics have on the theme. This section shows the considerable predominance of certain countries in terms of the number of publications on specific topics, such as: Finland for forest biomass (cluster 1); Malaysia for palm oil (cluster 8); Brazil for straw (cluster 9), and the USA for corn biomass (cluster 10).

3. Countries with the most bioeconomy-related publications

Figure 37: Evolution of publications for the 5 countries that publish the most.

Figure 37 presents the evolution of the number of articles from the 5 countries that have published the most since the onset of the 21st century, according to the network generated from the WoS database. It is clearly visible that the increase in the number of publications occurred in the mid-2000s and there has been an upward trend since then. It is also worth highlighting the considerable growth in the number of publications originating from Germany and China from 2014 onwards. The results for each of the five countries analyzed are presented below.

3.1. The United States of America

With a total of 896 articles, the USA has the highest number of publications, accounting for 19% of the network. The keyword ranking for the US is similar to the keyword profile of the complete network word cloud (Fig. 4), in that the **biofuel** and **bioenergy** sectors are the most prominent in the set of publications (Fig. 38).

	Keywords	total
1ª	biofuel	237
2ª	biomass	212
3ª	bioenergy	136
4ª	biorefinery	59
5ª	bioeconomy	36
6ª	nitrogen	33
7ª	cellulosic ethanol	33
8ª	biochar	25
9ª	feedstock	21
10ª	biodiversity	20

Figure 38: USA word cloud.

More specifically, the analysis of US publications showed considerable focus has been given to the use of corn biomass and its co-products (cluster 15), primarily relating to cellulosic ethanol generation. Another theme notably explored is the use of grasses, mainly of the species *Miscanthus x giganteus* (cluster 3), and forest biomass (cluster 1) for bioenergy production. Of the 896 publications, 314 (35%) involved partnerships with other countries, the three most prominent being with China (17%), Canada (10%) and Brazil (3%).

3.2. Germany

Figure 39 shows the keyword cloud generated for publications originating from Germany. The country produced a total of 494 articles, comprising 11% of the network, of which 206 were produced in cooperation with other countries. This cooperation was widely distributed, with even the main partners having a low level of participation: Italy (4%), Holland (3%) and China (3%).

	Keywords	total
1ª	biomass	121
2ª	bioenergy	68
3ª	biofuel	68
4ª	bioeconomy	61
5ª	innovation	29
6ª	biorefinery	28
7ª	land-use	24
8ª	biogas	22
9ª	impact	16
10ª	sustainability	16

Figure 39: Germany word cloud.

In contrast to what was observed for the USA, where there was a strong concentration in specific clusters, the German publications in the network were more broadly distributed in terms of theme. It is worth mentioning the studies associated with biogas production and impacts on land use.

3.3. Italy

Figure 40 shows the theme ranking and corresponding keyword cloud for Italy-based publications. The country produced 399 articles, corresponding to 9% of the network. It is worth mentioning 3 areas with a relevant number of publications: use of grass biomass (clusters 2 and 13); the production and use of olive oil and its co-products; and sewage/effluent processing, mainly by anaerobic digestion.

	Keywords	total
1ª	biomass	111
2ª	biofuel	43
3ª	biorefinery	36
4ª	bioeconomy	36
5ª	waste	34
6ª	bioenergy	31
7ª	anaerobic-digestion	25
8ª	sustainability	20
9ª	nitrogen	13
10ª	biodiversity	12

Figure 40: Italy word cloud.

Forty-five percent of the Italian publications were in cooperation with other countries. The three countries that cooperated with Italy the most were: Germany (8%), Greece (5%) and Portugal (5%).

3.4. China

Articles from China (336) represented 7% of the network, 190 of which (57%) were in cooperation with other countries. The country that published the most in partnership with China was the USA (27%), followed by Canada (5%) and Taiwan (4%). The keyword cloud for China (Fig. 41) shows similarly to that of Germany, as the Chinese publications were widely spread across different clusters of the network, albeit with a relevant presence highlighted in the topics of effluent/sewage biodigestion and levulinic acid production.

	Keywords	total
1ª	biomass	84
2ª	biofuel	50
3ª	biorefinery	30
4ª	bioenergy	30
5ª	biochar	21
6ª	biogas	12
7ª	chlorella-vulgaris	11
8ª	anaerobic-digestion	11
9ª	biogas production	10
10ª	co-digestion	9

Figure 41: China word cloud.

3.5. England

England-based publications (294) accounted for 6% of the network (6%), 175 (60%) of which were in cooperation with other countries. The three countries that published the most with England were: the USA (5.1%), Italy (4.6%) and Scotland (4.6%). Interesting points of note in the keyword cloud for English publications (Fig. 42) are the words "Brazil" and "sugarcane bagasse", reflecting a body of work in partnership with Brazil concerning the use of sugar cane bagasse in second-generation ethanol production.

	Keywords	total
1ª	biomass	57
2ª	biofuel	44
3ª	bioenergy	33
4ª	bioeconomy	31
5ª	biorefinery	24
6ª	innovation	13
7ª	waste	13
8ª	challenges	12
9ª	biotechnology	9
10ª	politics	8

Figure 42: England word cloud.

The English publications were also widely distributed across the network; however, it is possible to highlight publications involving the use of grasses for bioenergy and political-economic evaluation involving the bioeconomy and circular economy.

4. Brazil

This section presents the results of Brazilian publications in the network, with Fig. 43 illustrating the evolution of the 10 countries with the most bioeconomy-related publications and Brazil (in 11th place). There has been a clearly visible upward trend of rapid growth for Brazil in the bioeconomy field since 2016.

Figure 43: Top 11 countries with bioeconomy-related publications.

The keyword cloud for Brazilian publications (Fig. 44) highlights particular focus in the production of biofuels and bioenergy, mainly from sugar cane biomass. The predominance of Brazil in cluster 9 reflects this focus. However, it is worth noting that Brazilian publications were also widely spread across the network.

	Keywords	total
1ª	biomass	55
2ª	biofuel	41
3ª	biorefinery	31
4ª	bioenergy	25
5ª	brazil	18
6ª	sugarcane bagasse	17
7ª	sustainability	12
8ª	bioeconomy	12
9ª	waste	10
10ª	Cellulosic ethanol	9

Figure 44: Brazil word cloud.

Brazilian publications account for a total of 215 articles in the network (5%), of which 42% were in partnership with other countries. The graph (Fig. 45) and map (Fig. 46) below detail Brazil's main publication partners and provide a geographic representation of partner location, respectively.
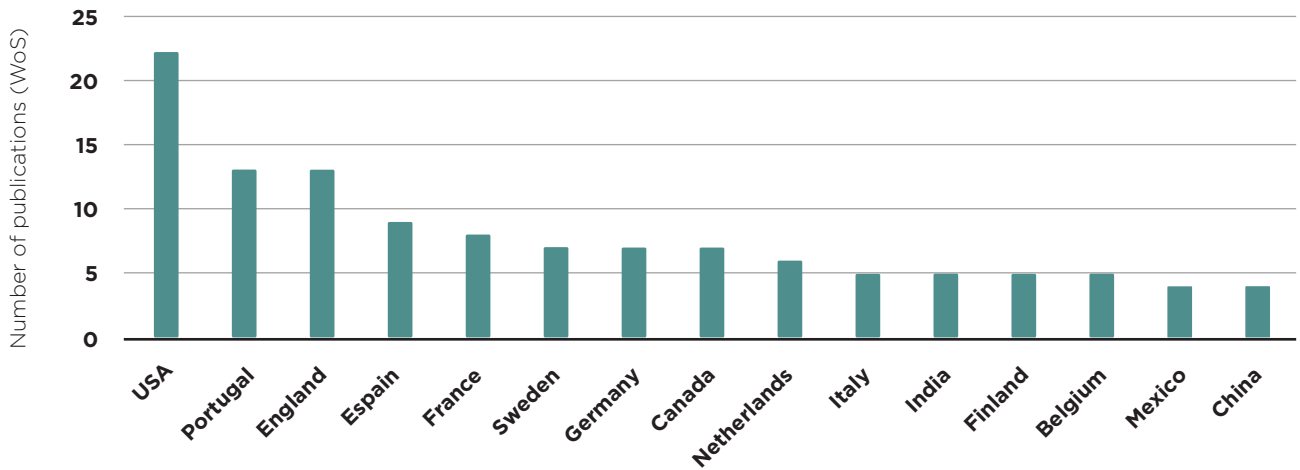
Figure 45: Brazil's main publication partners.
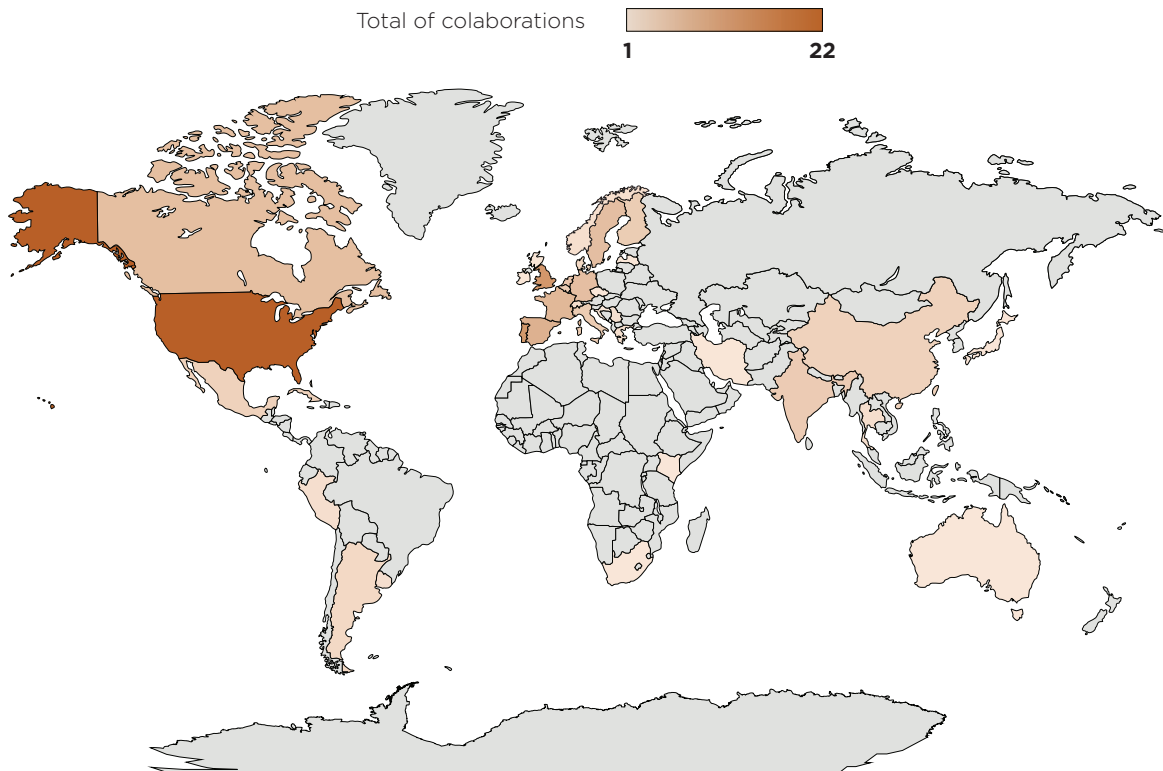
Figure 46: A geographic representation of Brazil's main publication partners.

Figure 47 details the 15 organizations with the most bioeconomy-related publications in Brazil, 12 of which are federal/state universities. It is worth mentioning Embrapa and CNPEM are research institutions with a strong role in the bioeconomy field.

Figures 48 and 49 show the distribution of Brazilian bioeconomy-related publications according to state. These figures highlight the dominance of the Southeast region in terms of scientific production within this field, especially the state of São Paulo. Considering the huge

degree of biodiversity that exists throughout the national territory, this result highlights the need for more STI institutions focusing on the bioeconomy outside the southeastern region.
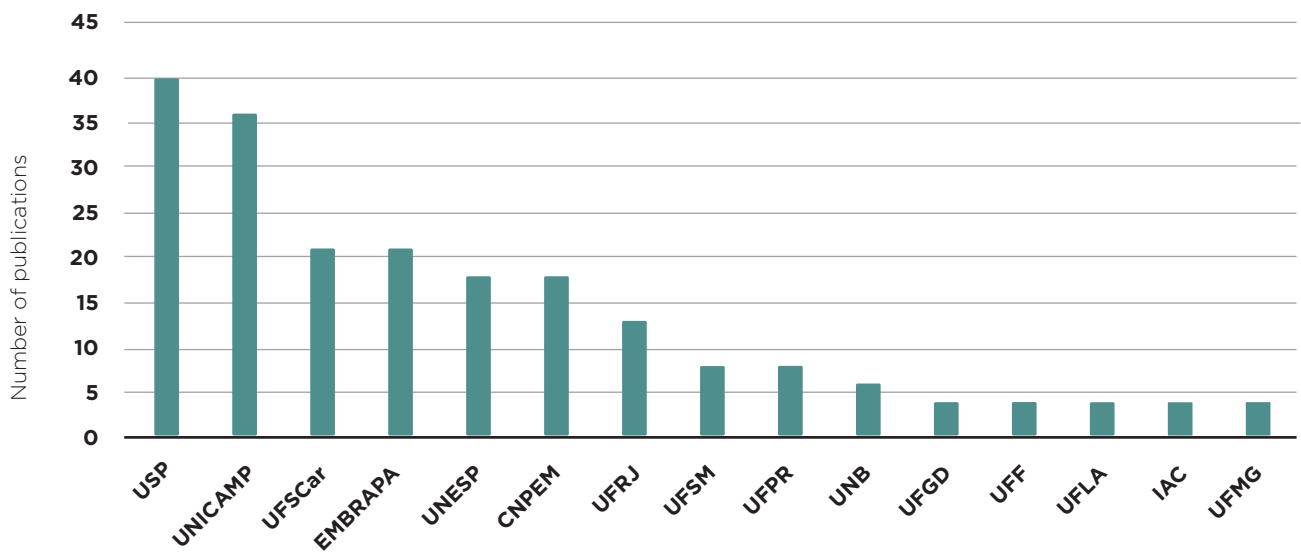
Figure 47: Principal institutions with bioeconomy-related publications in Brazil.
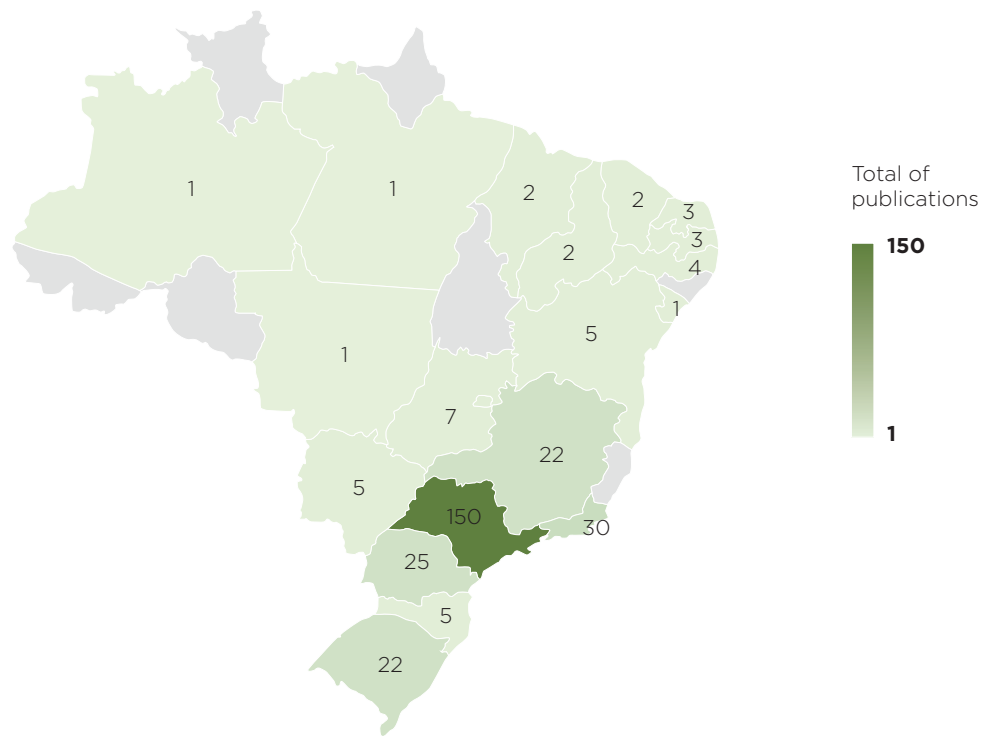
Figure 48: Origin of bioeconomy-related publications in Brazil according to state.
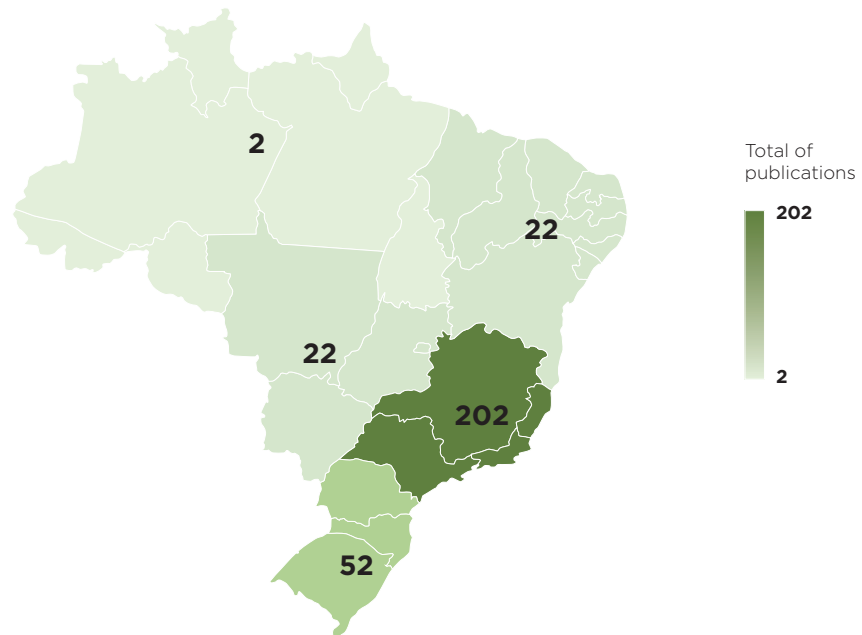
Figure 49: Origin of bioeconomy-related publications in Brazil according to region.

5. Final considerations

This report presented the results of a semantic similarity network constructed using the **snowball** methodology from the word - **bioeconomy**. The results mainly emphasized: the influence of regional characteristics on the types of bioeconomic publications, the predominance of the biofuel and bioenergy sectors in the field, and the importance given to addressing the bioeconomy using biomass or renewable raw materials. The specific results for Brazil showed how the country has stood out in recent years regarding its number of pertinent publications. The results also showed that domestic bioeconomic research remains highly concentrated in the Southeast region of the country, more specifically in the state of São Paulo.

The data collected herein presents some limitations, including the use of a single database (Web of Science); a methodology based on a small initial sample set (1675 articles); and only partial characterization of the network (15 clusters). Forthcoming issues will aim to reduce the limitations of bioeconomy studies by considering additional data sources, such as other scientific and patent databases, thereby broaden the scope of the research in this field.

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