Brazilian Scientific and Technological Production on Carbon Materials: an Exploratory Study (2010–2022)

Mayara B. Leão[1], Gabriele Züge[1], Carolina F. M. Jauris[1]

[1]Centro de Ciência e Tecnologia Ambiental, Campus Caçapava do Sul, Universidade Federal do Pampa (Unipampa), 96570-000 – Caçapava do Sul – RS – Brazil.

mayarabitencourtleao@gmail.com, gabrielezuge.aluno@unipampa.edu.br, carolinamatos@unipampa.edu.br

Abstract. *Carbon has been widely studied worldwide, mainly due to its numerous application possibilities. Despite this, no studies statistically report the realization of these studies in Brazil. In this sense, the objective of this work was to carry out a statistical survey of works with carbon materials published by Brazilian authors between 2010 and 2022, using the Web of Science platform. In addition, patents filed with the INPI were evaluated. The results showed that the country is the 15th country globally with the highest number of publications with carbon materials; however, a decrease in the number of publications was observed in the last three years and a great disproportion between the five Brazilian regions.*

1. Introduction

Carbon is one of the fundamental elements in nature, being used for over 3000 years, but with significant advances in recent decades due to reports and development of new carbon-based materials, such as fullerene, carbon nanotubes, and more recently, the graphene (Liu et al. 2021). The carbon atom can form single, double, or triple bonds, bonding to itself or other elements (Zarbin and Oliveira 2013). Due to this ability to form different bonds, it can be found in different stable allotropic forms, ranging from natural structures such as diamond, amorphous carbon and graphite to artificially synthesized carbon nanotubes, fullerene and graphene (Matos et al. 2017).

These carbon-based materials play a vital role from a technological, industrial, social, and economic point of view. Brazil is one of the world's main producers of scientific knowledge in the carbon area, with a large installed capacity, mainly in universities and in some research centers that meet and promote the demands in the area (Sabzehmeidani et al. 2021). Studies with graphite materials have been developed in this country at least since the 1990s. With the graphene isolation in 2004, these studies were intensified, as there was already a prior research infrastructure and human resources to work with this material. Furthermore, the creation of the National Network of Carbon Nanotubes (2005) and the Institute of Science and Technology of Carbon Nanomaterials (2009) allowed the exchange of knowledge and infrastructure between researchers across the country, leading to an exponential growth of patents and articles published in this area (Pimenta et al. 2019, Bellucci et al. 2021).

Several factors have limited this growth despite the previously reported growth in recent years. The main one, without a doubt, is the budgetary insufficiency, which is increasingly present in Brazilian universities and research institutions (McManus and Neves 2021),

leading to reduced research possibilities and the general collapse of the system. In addition, due to the socioeconomic and cultural differences in Brazil, scientific and technological behavior can present significant differences when compared between the regions of the country. Therefore, understanding the behavior and profile of researchers and research carried out with carbon materials over the years allows directing efforts to obtain greater scientific homogeneity for the different regions of the country.

With international prominence, Brazilian scientists have made significant contributions to the science and applications of carbon materials (Pimenta et al. 2019). However, no review has statistically reported simultaneously the number of articles published, the behavior of the number of publications over the years, the main materials studied, and the scientists who carry out these studies. In this sense, to assess the current scenario of Brazilian scientific and technological production, this review presents a critical analysis of data referring to statistics of articles and patents on carbon materials published by Brazilian authors between 2010 and 2022. In addition, it evaluates production by region of the country. It comprises the central lines of studies that approach carbon in developing new materials, new production methods, characterization, and performance evaluation. In addition, a survey was carried out on the presence of women among the authors with the most significant number of published articles.

2. Experimental Procedure

The selection of articles was performed using the Web of Science search platform. Initially, on 11/21/2021, the search for "Carbon Material*" was performed in the Topic field with a date range defined between 01/01/2010 and 03/31/2022. The asterisk was used as a truncation operator to include the terms "material" and "materials" in the same search. Subsequently, document filters were used, selecting the option "article" and by country/region, selecting the option "Brazil," as shown in the flowchart in Figure 1.

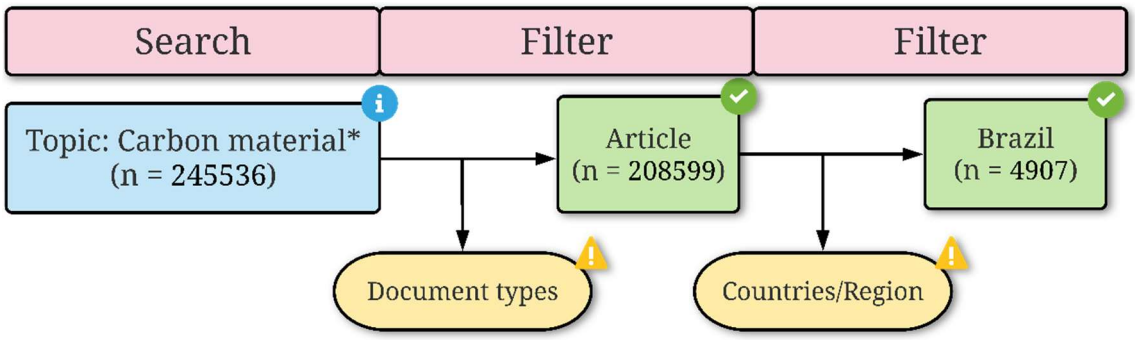

Figure 1. Flowchart of obtaining articles of carbon materials published in Brazil.

To obtain the types of materials that are present in these articles, the search field "Search within results for" was used, where the terms "fullerene*", "graphene*", "graphite*", "carbon nanotube", "fiber*", "dots", "carbon black" and "activated carbon" were typed individually. Finally, the remaining data were obtained using the "Analyze Results" tool. Patents filed between 2010 and 2021 in Brazil were obtained on the website of the National Institute of Industrial Property (INPI) (Instituto Nacional da Propriedade Industrial 2021) from a basic search for the terms in Portuguese "material de carbono", "materiais de carbono", “carvão ativado”, "grafite", “grafeno”, “fulereno” and “nanotubos de carbono” in the title field and containing all the words. Data were selected and

processed through individual access to the files of each patent. Data on the gross domestic product (GDP) by region were obtained from the Brazilian Institute of Geography and Statistics (IBGE) website. All figures were constructed from the data obtained in the search performed. The maps of Brazil and its regions were constructed using the free online tool MapChart (MapChart 2021). The other graphs were built with the help of specific software. The Sankey diagram was built with the same software using the "Sankey" tool.

3. Results and Discussion

3.1. Studies with carbon materials in Brazil

About 4.907 articles that met the selection criteria were found from the search performed. This result places Brazil in 15th place among the countries that publish the most scientific articles on carbon materials globally, with 2.35% of the articles published in the selected period. In order to assess the placement of Brazil regarding other countries in the number of articles published, we compare the placements with the GDP of each country, according to the International Monetary Fund (IMF). The trend is that the higher the country's GDP, the greater the number of scientists who publish more impact articles. An example is Brazil itself, which is in 15th place in the production of articles and is the 12th economy of the world, with a GDP of 1444,718 billion dollars (International Monetary Fund 2021).

According to the year of publication (Figure 2a), from 2010 to 2020, we observed an increasing number of publications; however, there was a decrease in the growth rate of publications over the years. In 2021, the number of publications was below 2019 and 2020. The limited rate of increase and the decrease in the number of articles published in 2021 can be attributed to experimental limitations imposed by the COVID-19 pandemic (Nature 2021) and the decrease in scientific funding.

Quite different behavior could be found earlier. A survey carried out by FAPESP in 2010 showed that the Brazilian contribution to world scientific production rose from 1.6% in 2002 to 1.9% in 2006. In addition, there was a 43.5% growth in the number of Brazilian publications in the period, twice the world growth of 22.7% (Brentani et al. 2011). In 2011, Brazil jumped to 13th place in the global carbon papers scenario; however, this trend was reversed. Although the Brazilian scientific production has grown at a constant rate of 16% between 2011 and 2014, it fell 4% in 2015 (Angelo 2016). This happened because Brazil's main scientific development agencies have had their budgets cut in recent years. Such cuts resulted in many laboratories and research institutions being stagnant (Escobar 2019) due to the difficulty of acquiring new equipment and performing maintenance of previously acquired equipment. In addition, the cuts directly affect the number of scholarships available, especially for graduate students; this leads to a decrease in students in graduate programs and brain drain. Such factors result in a decrease in the number of publications, including for carbon materials.

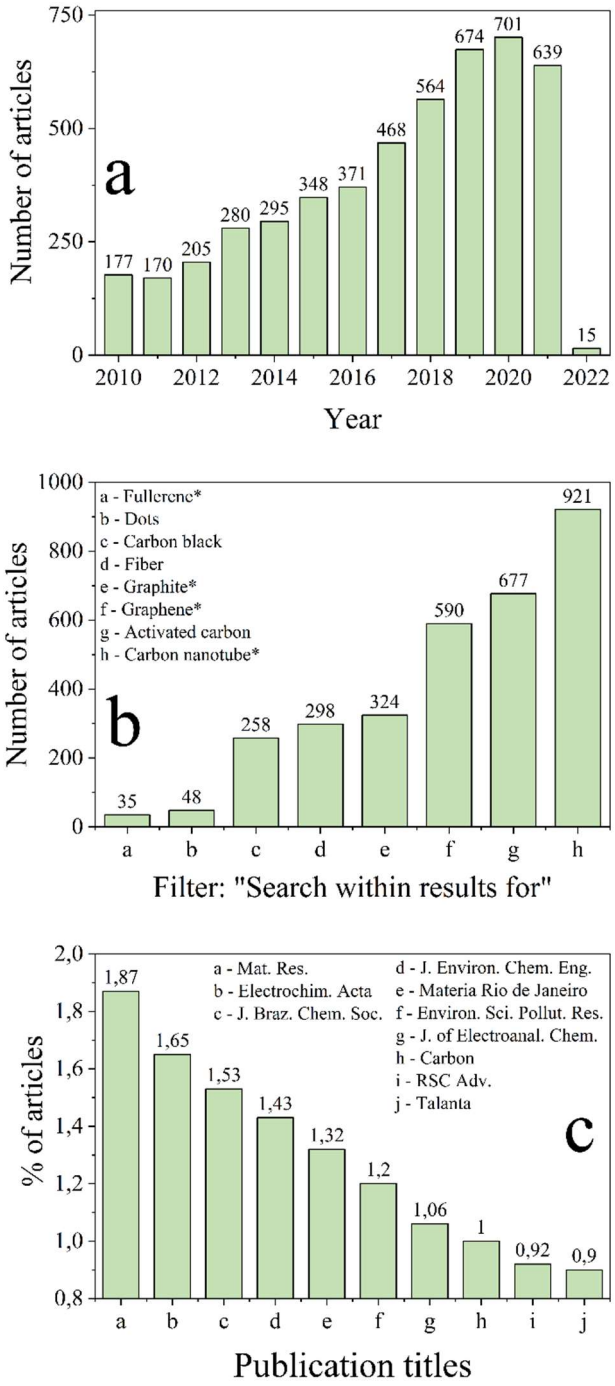

Figure 2. Analysis of publications results according to (a) year, (b) material and (c) journal.

The search filter "Search within results for" made it possible to evaluate the types of carbon materials studied in the evaluated period (Figure 2b). At this point, it is essential to note that a part of the articles may appear for more than one search, as there are many studies involving composite materials, which include more than one type of carbon material (e.g., graphene and carbon nanotubes). In general, it is observed that, among the materials selected for the search, there are many studies carried out with carbon nanotubes, followed by activated carbon and graphene, representing approximately

18.77%, 13.80% and 12.02% of selected articles, respectively. On the other hand, papers with graphite, fibers and carbon black appear in smaller quantities, with studies with carbon dots and fullerenes being rare. Compared with studies carried out worldwide, where the most studied materials are carbon nanotubes (24.41%), graphene (22.40%) and activated carbon (10.51%), it is possible to observe that Brazil has a smaller proportion of studies with carbon nanotubes and especially with graphene.

On the other hand, more studies are seen for activated carbons. This is probably due to the richness and diversity of biomass available in Brazil. A search for the term "biomass" among all the articles evaluated in this work shows the presence of this term in 11.1% of the articles. In addition, obtaining these materials is relatively simpler and cheaper when compared to obtaining other carbon materials, better adapting to the reality of Brazilian institutions.

About the periodicals where the articles are published, 1053 titles were found. The first 10 are shown in Figure 2c, and indicate that the three journals with the highest number of publications among the selected articles are Materials Research (specialized in materials), where about 1.87% of the articles are published, Electrochimica Acta (specialized in electrochemistry), with 1.65% of the articles, and Journal of the Brazilian Chemical Society (specialized in chemistry), which contains 1.53% of the articles published by Brazilian scientists. Since the journals specialized in electrochemistry and environmental sciences are the ones that receive the most significant number of publications, from the analysis of the journals where the articles are published, it is possible to observe, mainly, the applications that are given to these materials.

Figure 3a shows the participation of authors from other countries in the selected articles. It noted the significant participation of North American co-authors in 7.60 % and collaborations with researchers from France, Spain, Germany, Portugal, England, Italy, Canada, and India. The participation of authors from China, the country that most published articles on carbon materials in the same period, represents only 1.54% of the articles published. About 94% of the articles were published in English and just over 5% in Portuguese.

Comparing this study with the survey of international collaborations previously carried out by McManus et al. (2020) (McManus et al. 2020), among the countries that stand out in all areas, only India is not among the main Brazilian collaborations, indicating that partnerships with institutions in that country seem to be more related to carbon materials. An interesting point is the low amount of collaborations with Chinese institutions, despite the country being the largest producer of articles with carbon materials. This limitation is probably due to the language barrier, as English-speaking countries are at the center of global science. Furthermore, the English language for publication in internationally indexed journals generates greater international recognition. The most cited articles by Brazilian researchers are often published in collaborations with colleagues in the United States, England, and Australia (Martinez and Sá 2020).

When thinking about Latin America, Brazil has an excellent internal collaboration network, but with few external collaborations (McManus et al. 2020), remaining peripheral to global science, despite exercising regional leadership in the Latin American context. Previous studies show that among highly cited Brazilian researchers, most work in prestigious public universities and are inserted in international research networks, having international mobility at different stages of their careers (Martinez and Sá 2020).

International collaborations are essential for developing national research so that scientific isolation could cause a gradual financial and intellectual separation between national and international institutions (McManus et al. 2020).

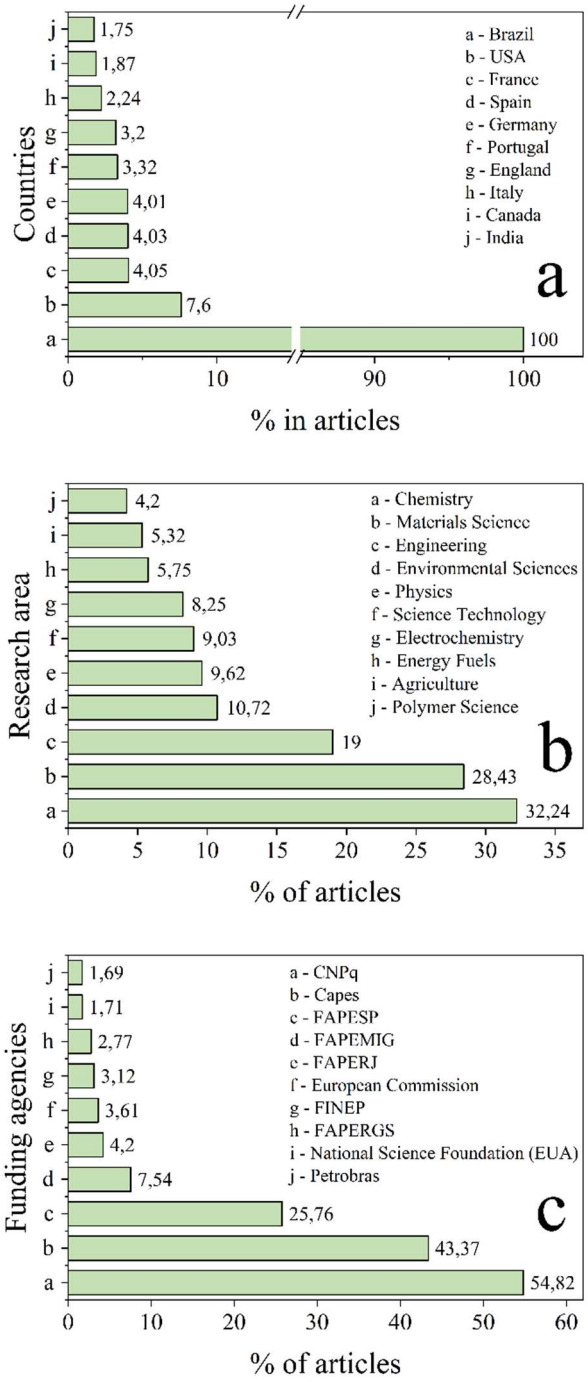

Figure 3. Analysis of publication results according to (a) country of authors, (b) area of knowledge and (c) funding agency.

The articles evaluated in this work are grouped in different areas and can be classified in more than one area simultaneously. The areas with the highest number of articles (Figure 3b) are, respectively, Chemistry (32.24%), Materials Science (26.43%), and Engineering

(19.00%). Also noteworthy are the researches carried out in the environmental sciences, in the area of physics, science and technology and electrochemistry. On the other hand, energy fuel, agriculture, and polymer sciences still appear with less representation. Likewise, the same article can have more than one funding source, with the most prominent agencies being CNPq, which financed 54.82% of the articles published, followed by Capes (43.37%) and FAPESP (25.76%), highlighting the importance of these sources of funding for carbon research in Brazil, despite the cuts suffered, as mentioned above (Figure 3c). Previous studies show that even with the emphasis on federal agencies, the São Paulo development agency (FAPESP) had a national impact due to the collaboration of researchers from other states with São Paulo universities. Furthermore, it was observed that works financed by Brazilian agencies were published in journals with a lower impact than those financed by foreign agencies. This highlights, once again, the importance of collaborations with international institutions (McManus and Neves 2021).

3.2. Regional behavior

The Brazilian territorial and historical formation is unequal for the different Brazilian regions. Territorial occupation and industrialization began on the coast, especially in the southeast and south, so it is expected that regions further away from these places will be socioeconomically harmed, which leads to a lower Human Development Index (HDI). Due to the continental dimensions and socioeconomic inequalities in Brazil, it is expected that the behavior of research and publications will vary according to the demographic region assessed. In a general context, it should be noted that demographic changes imply social and economic variations, which can result in negative or positive effects (Lazaretti et al. 2019), with scientific research being included in these variations

Figure 4 shows, in a representative way, the distribution of the 50 institutions that most appear in the affiliations of the authors of the evaluated articles. The majority presence of institutions located in the south and especially in the southeast is quite evident, so that the ten universities with the highest number of articles published are in these regions: USP, Unicamp, Unesp, UFSCar, UFRGS, UFMG, UFRJ, UFPR, UFSM, and UFSC, respectively. The two regions concentrate near 66% of the institutions that produce the most scientific articles. Among the 50 institutions with the highest number of publications, 6 of them are located abroad, namely: Center National de la Recherche Scientifique (France), which appears again as the CNRS Chemistry Institute, Helmholtz Association (Germany), United States Department of Energy (USA), Consejo Superior de Investigaciones Cientificas (Spain) and Consejo Nacional de Investigaciones Cientificas y Tecnicas (Argentina). Among the top 50 institutions, 44 are Brazilian institutions, with only one private institution, the University of Caxias do Sul, which appears in 45th place, indicating that most of the scientific knowledge on the subject is produced in public institutions. These data corroborate previous studies that show that almost all surveys in the country are carried out predominantly in public universities, which correspond to the realization of about 95% of Brazilian surveys (McManus et al. 2021).

Figure 4. Maps of the locations and the number of institutions that publish the most articles according to the search performed.

Performing an analysis by region, we observe in Figure 5 that the distribution of the 44 Brazilian institutions with the highest number of publications is entirely disproportionate in the 5 Brazilian regions, as is the case for 26 states and the Federal District. In Figure 5f we present the GDP for each of the five regions of the country, and we observe that the number of institutions with the highest number of publications is directly related to the region's GDP. A positive relationship between GDP per capita and public spending on research and innovation with the scientific and technological development of countries has already been observed. Therefore, a higher GDP per capita may indicate a greater willingness to invest in research and innovation (Esteves and Feldmann 2016). In addition, historical factors must be considered since the first Brazilian chemistry laboratories were installed in the Southeast region and much later were disseminated to other regions (Santos 2004). Previous studies show that among institutions that are among the first in terms of international collaboration, there is a higher prevalence among those located in the Southeast region, mainly in São Paulo and Rio de Janeiro. Fewer institutions from the poorest regions are among the top 20 in terms of international collaborations, which compromises the future of these regions and the country as a whole (McManus et al. 2020).

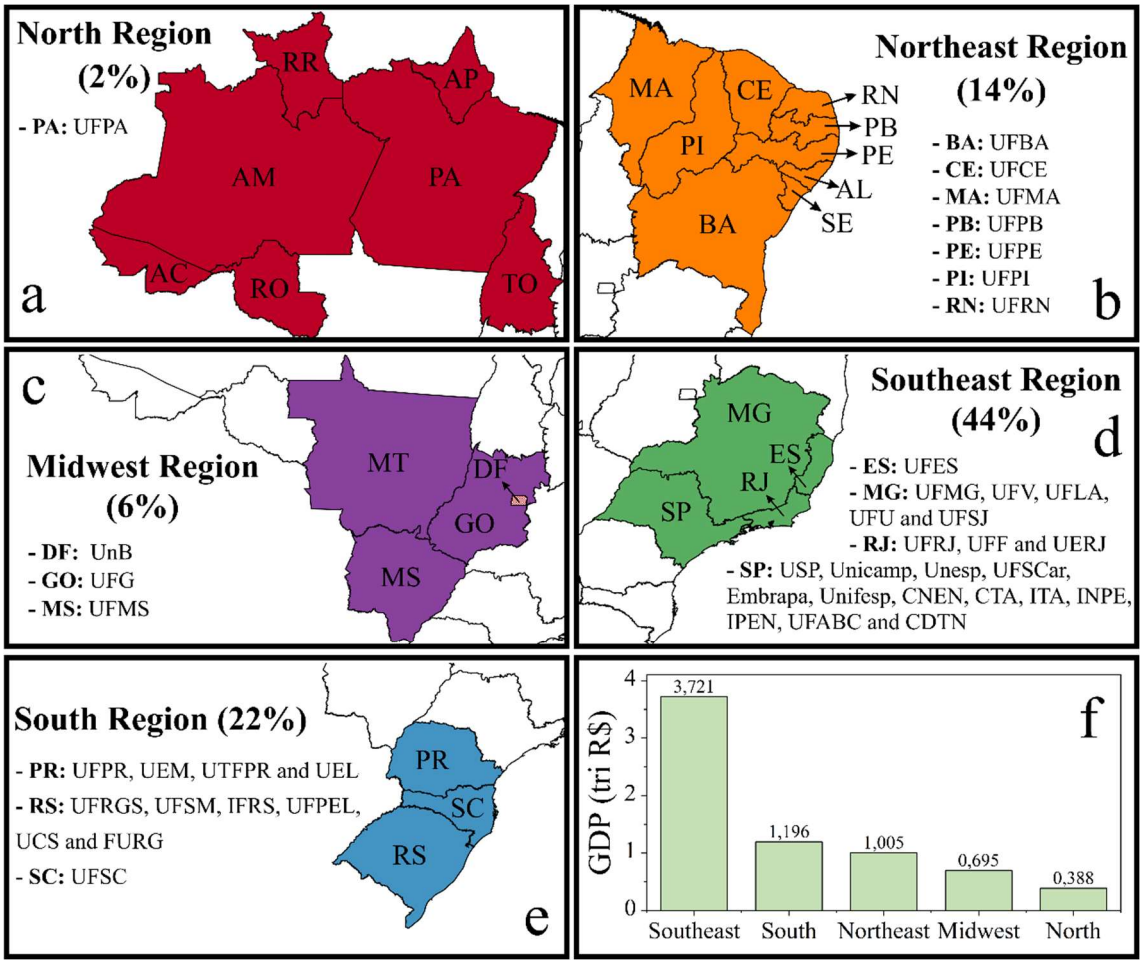

Figure 5. Distribution of the main research institutions for the regions (a) North, (b) Northeast, (c) Midwest, (d) Southeast and (e) South, and (f) graph with the GDP for each Brazilian region.

It is possible for each of these regions to observe that different material stands out among the most researched. The Sankey diagram, shown in Figure 6, outlines the materials surveyed for each region. For the Southeast region, the most studied materials are carbon nanotubes, graphene, and activated carbon. For the southern region, activated carbon, carbon nanotubes and graphene. In the Northeast region, carbon nanotubes, activated carbon and graphene. For the Midwest region, graphene, activated carbon and carbon nanotubes. Finally, activated carbon, carbon nanotubes, and graphene in the North region. Despite the different proportions, we observed that the three types of materials are the most studied in any region. It is even more evident that the disproportionate difference of studies published by the Southeast region, especially the South and Northeast, compared with the Midwest and North regions, verified by the width of the chord that has the origin on the right of the graph.

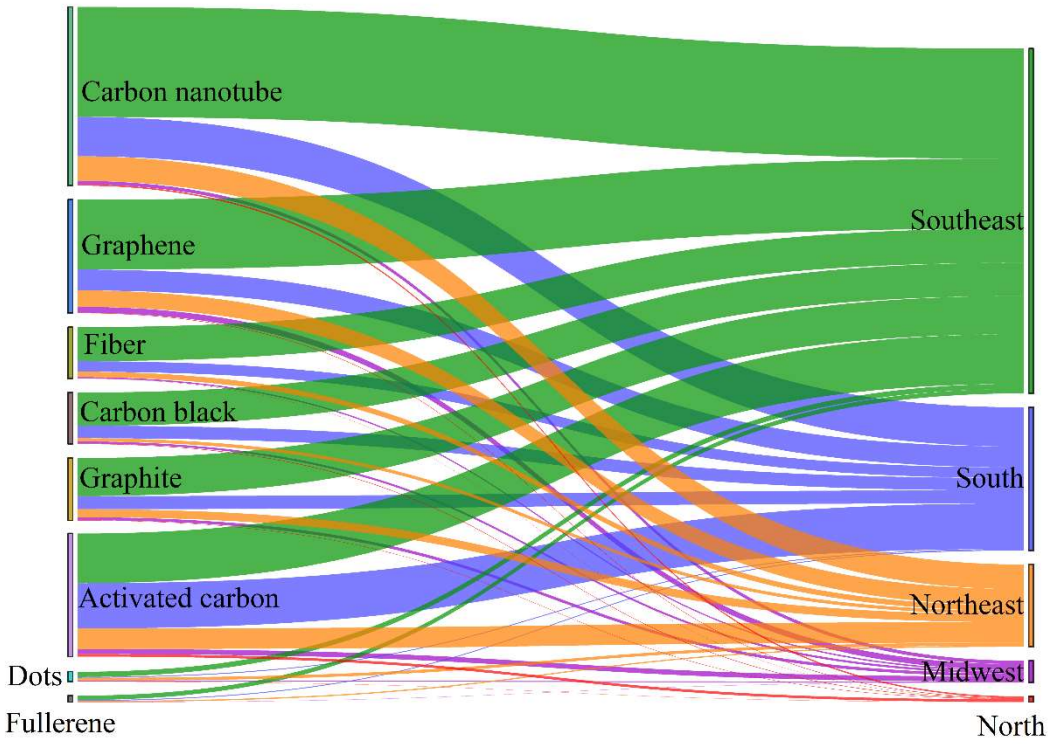

Figure 6. Sankey diagram, relating the variable material (carbon nanotubes, graphene, fibers, carbon black, graphite, activated carbon, carbon dots and fullerene) with the variable region (Southeast, South, Northeast, Midwest and North).

3.3. Women in carbon materials science

The continental dimension of Brazil, associated with regional differences, can directly affect scientific production. The disparity can become even more remarkable when observing the gender distribution of researchers who publish articles on carbon materials for each of the Brazilian regions evidenced in Figure 7, thus, demanding a critical analysis concerning the disproportionate of published articles concerning gender in the different regions.

The presentation of the researchers' spatial distribution that most contributes to publications in carbon area observed in Figure 7 exposes structural characteristics of the Brazilian innovation system, such as its concentration and regional inequality. An alarming fact concerning the authorship of these articles concerns the 25 researchers with the highest number of publications. Among these, only 2 are women (8%), corroborating the results of previous studies that show that male researchers dominate the areas of Chemistry and Engineering, with a significant disparity in the approach to the top of the career (Bezerra et al. 2019, Naideka et al. 2020). This inequality is also maintained globally, with a gender difference of 27% in total productivity, where male scientists, on average, publish 13.2 articles during their careers, while women publish only 9.6 (Huang et al. 2020). Furthermore, when it comes to female members in science academies in Brazil, China, France and the United States, there is a low percentage of 14%, 6%, 11% and 13%, respectively (Valentova et al. 2017).

It should be noted that the proportion of the economy and the level of economic growth, which are directly related to GDP, are key factors when evaluating scientific production by regions in Brazil (Pietrucha 2018). The regions with the highest to the lowest GDP in Brazil are the Southeast, South, Northeast, Midwest and North, respectively (Figure 5f). However, when analyzing the distribution of the female gender in relation to the male researchers who publish the most articles on carbon materials (Figure 7), it is observed that the south is at the top of the list with 28% of women, followed by the North (24%), Northeast (16%), Midwest (6%) and, what draws attention, the southeast at the end of the list, with 5% of female participation. This calculation was performed based on the names of the 25 researchers with the highest number of publications in the period evaluated. In some cases, it was not possible to verify the gender of the researcher due to the duplicity of the initials, and the author was not counted in any of the genres.

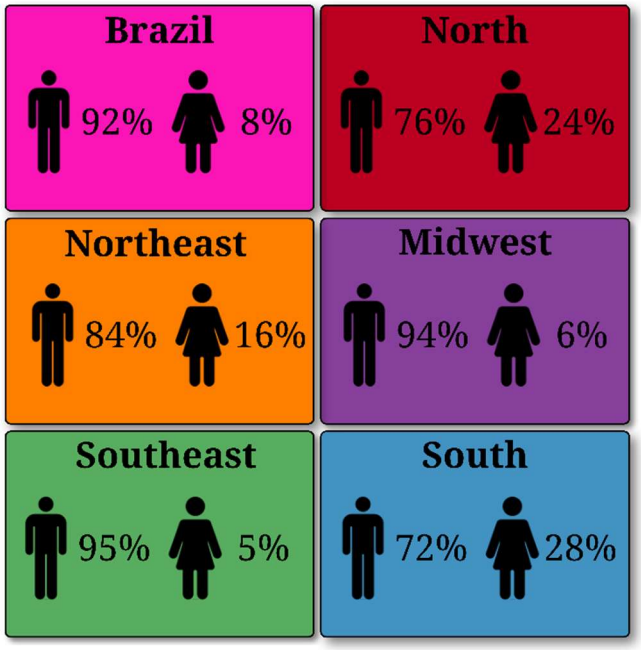

Figure 7. Gender distribution of the 25 researchers who publish the most articles on carbon materials in Brazil and for each of the country's regions.

Despite previous studies reporting a misogynistic bias towards the North region (Biasao et al.), this region has a greater female contribution in carbon publications. Another region in which women have stood out is the south, with seven researchers with the most outstanding contribution in the publication of articles in the carbon area, and stands out compared to the Southeast region, which has only one researcher actively contributing in the area. When looking at the publications of articles by men, the region with the highest percentage is the southeast (95%), showing an abyss and huge disproportionality in relation to gender, indicating that the inequality in the country is not simple. Numerous variables can be correlated, making this analysis very complex. One of the answers may lie in the very structural system of universities, where the issue of stereotypes still predominates, which historically associated women with a lower intellectual development than men in the exact sciences (Bian et al. 2017). This issue of stereotypes has been dismantled, and every day the representation of women advances in different areas of the scientific career (Ferrari et al. 2018).

A study by Naideka et al. (Naideka et al. 2020) showed a decrease in this female representation as the level of the position increases, taking as an example the levels of productivity that a scientist can achieve, women are found at 28% for 1D, 31% for 1C and 21% for 1B and just 12% for 1A, the highest level of productivity subsidies. Similarly, the Royal Society of Chemistry reported that 44% of chemistry students are women in the UK, which drops to just 9% for professors (Kundu 2019). This effect of decreasing women in higher career positions may be associated with the life span of these women and their choices, such as the period of motherhood and/or temporary dedication of the family to domestic and/or parental care. Thus, this interruption in the professional trajectory allows male scientists better qualifications and greater scientific production (Soares and Naegelle 2021). This disparity was further exacerbated during the pandemic caused by the SARS-CoV-2 virus (Staniscuaski et al. 2020).

The unequal scenario also aggravates the "brain drain" (Hipólito et al. 2021), which consists of the national or international migration of highly qualified individuals, resulting in the transfer of human capital and knowledge base for technological improvements to the region of installation (da Silva Freguglia et al. 2019). It may be one of the factors for the low percentage of women who publish articles in Brazil. Valentova et al. (2017) (Valentova et al. 2017) highlight that factors such as disproportionate access to jobs, opportunities and research grants, in addition to the lack of recognition of scientific discoveries, make researchers migrate to other places or even leave the academy. Overall, this disparity has many negative effects, as we are probably losing the wealth of ideas that a more diverse group of people would bring (Kundu 2019), limiting scientific progress due to the lack of representation of women in science.

3.4. Patents for carbon materials registered in Brazil

The development and progress depend on the scientific and technological innovation produced by its institutions. One of the ways to measure a country's innovation is through patents (Ruijie et al. 2021), which provide information on state of the art in the technology field (Drake 2019). Patents are industrial property titles on the invention of a product or a new utility model (Amadei and Torkomian 2009), and form an integral component of local and global economies, a pillar in the commercialization of innovations and an essential source of technical literature (Sigmon 2021). In this sense, since innovation is a crucial indicator of a nation's economic progress (Drake 2019), we included in this study a brief search on patents filed and registered on the National Institute of Industrial Property (INPI) website in order to compare with the results obtained for the articles published by Brazilian authors.

Figure 8 (a) shows the number of patents per filing year in the results from the search specified in the Experimental Procedure topic. Except for the year 2014, when fewer patents were filed than usual, we observed an increasing behavior of filings until the year 2016. After that, there was a gradual decrease until the year 2020. Few patents were found for the year 2021, due to the time required between filing and publication of the patent. In Figure 8 (b), the data referring to the location of depositing institutions are presented. The highlight for the southeast region, followed by the south region, is observed, as is the case for the number of articles published. The North region stands out in filing patents, with a much higher proportion than that of articles, concluding that this region seems to be more linked to the development and registration of new technologies. For this figure, it should be considered that more than one institution that may be located in different

regions of the country registers some patents. In this way, the sum of the values exceeds 100%.

As for materials, 81 patents were found that present the terms "material/materiais de carbono" in the title, 132 for "grafeno", 82 for "nanotubos de carbono", 68 for "grafite", 52 for "carvão ativado" and 8 for “fulereno”. There are more foreign patents than Brazilian patents for most materials, except for patents on activated carbon, which Brazilian researchers almost entirely file.

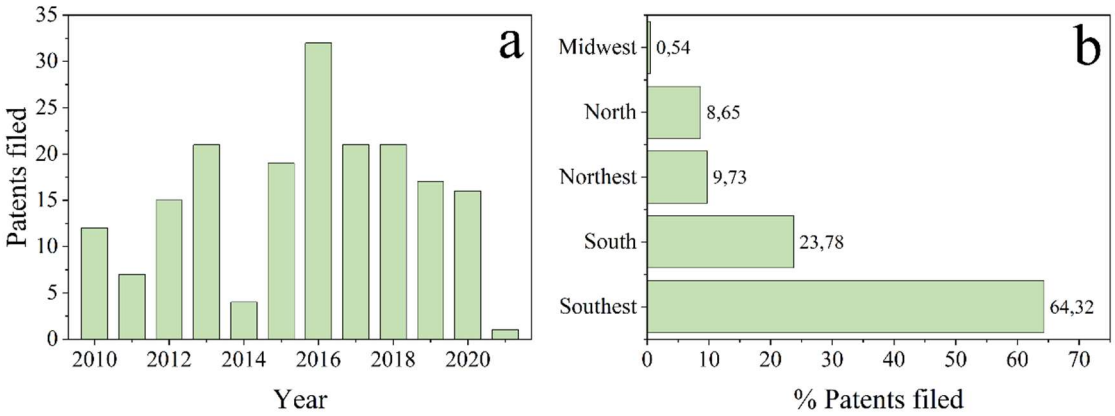

Figure 8. Data on patents registered at the National Institute of Industrial Property (a) by year of filing and (b) by Brazilian region of origin.

423 filed patents were found for the search carried out, 42.1% of which were filed by national institutions and 57.9% by foreign institutions. Of those published by institutions in other countries, most are deposited by countries in Anglo-Saxon America (49.8%), followed by countries in Europe (34.3%), Asia (11.4%), Oceania (3.3%) and Latin America (1.2%). Despite this, few Brazilian collaborations with foreign institutions were registered. We observe that patents filed by foreign institutions are mainly from the private sector, looking more closely and individually. On the other hand, Brazilian public universities make up almost all of the depositing Brazilian institutions, reinforcing, once again, the information that Brazilian public universities are the largest producers of scientific and technological knowledge.

4. Conclusions

From the results obtained, it was possible to verify the importance of Brazil in the world context, as it is the 15th country that publishes the most scientific articles with studies involving carbon materials. Among the materials studied stand out carbon nanotubes, activated carbon, and graphene materials. However, since 2019, there has been a decrease in the number of articles and patents published by Brazilian authors, possibly related to budget cuts made in recent years, since for both, almost all notable institutions are public.

The vast majority of researchers who obtain more prominence in research on carbon materials are men. Relevant differences for each country region were found, both for the percentage of women who publish the most scientific articles and the number of publications in general. Furthermore, the number of publications by region varies significantly, clearly exposing the country's socioeconomic differences. After analyzing all these data, it is evident that for Brazil to become a leading player in the carbon area,

massive investments in scientific research, public institutions and affirmative action policies for women in science will be necessary.

5. Acknowledgment

This work was carried out with the support of the National Council for Scientific and Technological Development (CNPq), processes n° 424146/2018-5 and 141896/2020-5. Coordination for the Improvement of Higher Education Personnel (CAPES, financing Code 001), National Institute of Science and Technology of Carbon Nanomaterials (INCT Nanocarbono) and Research Support Foundation of the State of Rio Grande do Sul (FAPERGS) process 21/2551-0000736-2.

References

Amadei, J. R. P. and A. L. V. Torkomian (2009). "As patentes nas universidades: análise dos depósitos das universidades públicas paulistas (1995-2006)." Ciência da Informação 38: 9-18.

Angelo, C. (2016). "Demotion of science ministry angers beleaguered Brazilian researchers." Nature News 533(7603): 301.

Bellucci, F., H. Vasquez and J. Conti "Panorama Tecnológico Grafeno."

Bezerra, G., D. Lazzaro, A. Peixoto and M. M. Lopes (2019). "Female Researchers in Science in Brazil: the Scissors Effect." La Brecha de Género en Matemática, Computación y Ciencias Naturales. Orgs. Montes, LM & and Dawson, SP Sociedad Mexicana de Fisica.

Bian, L., S.-J. Leslie and A. Cimpian (2017). "Gender stereotypes about intellectual ability emerge early and influence children's interests." Science 355(6323): 389-391.

Biasao, B. C., M. B. Valle, L. Barbosa and S. S. Tezuka "Geografia da mulher: Uma análise sobre a condição da mulher no Brasil."

Brentani, R. R., C. H. d. B. Cruz, W. Suzigan, J. d. M. Furtado and R. d. C. Garcia (2011). "Em Indicadores de Ciência, Tecnologia e Inovação em São Paulo 2010." São Paulo: FAPESP.

da Silva Freguglia, R., E. Gonçalves and R. H. de Paula Dutra (2019). "Fuga de cérebros no mercado de trabalho formal das cidades brasileiras: uma análise de dados em painel para o período 1995-2008." Planejamento e Políticas Públicas(53).

Drake, K. (2019). "Why we should care about patents." C&EN Global Enterprise 97(38): 38-38.

Escobar, H. (2019). "Brazilian scientists lament 'freeze'on research budget." Science 364(6436): 111.

Esteves, K. and P. R. Feldmann (2016). "Why Brazil doesn't innovate: A comparison among nations." INMR-Innovation & Management Review 13(1): 63-82.

Ferrari, N. C., R. Martell, D. H. Okido, G. Romanzini, V. Magnan, M. C. Barbosa and C. Brito (2018). "Geographic and gender diversity in the Brazilian Academy of Sciences." Anais da Academia Brasileira de Ciências 90: 2543-2552.

Hipólito, J., L. T. Shirai, L. M. Diele-Viegas, R. Halinski, C. S. Soares Pires and E. M. G. Fontes (2021). "Brazilian budget cuts further threaten gender equality in research." Nature ecology & evolution: 1-1.

Huang, J., A. J. Gates, R. Sinatra and A.-L. Barabási (2020). "Historical comparison of gender inequality in scientific careers across countries and disciplines." Proceedings of the National Academy of Sciences 117(9): 4609-4616.

Instituto Nacional da Propriedade Industrial, I. (2021). "Patentes." 04 de janeiro de 2021, from https://busca.inpi.gov.br/pePI/jsp/patentes/PatenteSearchBasico.jsp.

International Monetary Fund, I. M. F. (2021). "GDP, current prices ", from https://www.imf.org/external/datamapper/NGDPD@WEO/OEMDC/ADVEC/WEOWORLD.

Kundu, S. (2019). Women in chemistry, Nature Publishing Group.

Lazaretti, L. R., F. O. Teixeira and S. V. d. Oliveira (2019). "Desigualdades socioeconômicas e demográficas nos municípios do Rio Grande do Sul/Brasil: um índice de vulnerabilidade à pobreza." urbe. Revista Brasileira de Gestão Urbana 11.

Liu, F., Y. Cheng, J. Tan, J. Li, H. Cheng, H. Hu, C. Du, S. Zhao, Y. Yan and M. Liu (2021). "Carbon Nanomaterials With Hollow Structures: A Mini-Review." Frontiers in Chemistry 9.

MapChart. (2021). "MapChart: Create your own custom map." Retrieved 28/11/2021, from https://mapchart.net/index.html.

Martinez, M. and C. Sá (2020). "Highly cited in the south: International collaboration and research recognition among Brazil's highly cited researchers." Journal of Studies in International Education 24(1): 39-58.

Matos, C., F. Galembeck and A. Zarbin (2017). "Nanocompósitos multifuncionais de látex de borracha natural e nanoestruturas de carbono." Revista Virtual de Química, Curitiba: 73-96.

McManus, C. and A. A. B. Neves (2021). "Funding research in Brazil." Scientometrics 126(1): 801-823.

McManus, C., A. A. B. Neves, J. A. Diniz Filho, A. Q. Maranhao and A. G. Souza Filho (2021). "Profiles not metrics: the case of Brazilian universities." Anais da Academia Brasileira de Ciências 93.

McManus, C., A. A. B. Neves, A. Q. Maranhão, A. G. Souza Filho and J. M. Santana (2020). "International collaboration in Brazilian science: financing and impact." Scientometrics 125(3): 2745-2772.

Naideka, N., Y. H. Santosa, P. Soaresa, R. Hellingera, T. Hacka and E. S. Orth (2020). "Mulheres cientistas na química brasileira." Química Nova 43: 823-836.

Nature (2021). "COVID is disrupting scientific careers around the world." Nature 599(7884): 179.

Pietrucha, J. (2018). "Country-specific determinants of world university rankings." Scientometrics 114(3): 1129-1139.

Pimenta, M. A., L. A. Geracitano and S. B. Fagan (2019). "History and national initiatives of carbon nanotube and graphene research in Brazil." Brazilian Journal of Physics 49(2): 288-300.

Ruijie, Z., X. Ying, J. Shuaichen and L. Yonghe (2021). "Patent text modeling strategy and its classification based on structural features." World Patent Information 67: 102084.

Sabzehmeidani, M. M., S. Mahnaee, M. Ghaedi, H. Heidari and V. A. Roy (2021). "Carbon based materials: a review of adsorbents for inorganic and organic compounds." Materials Advances 2(2): 598-627.

Santos, N. P. d. (2004). "Laboratório químico-prático do Rio de Janeiro: primeira tentativa de difusão da Química no Brasil (1812-1819)." Química Nova 27: 342-348.

Sigmon, A. J. (2021). "Incorporating Patents into the Chemistry Curriculum: Insights from the Design of an Interdisciplinary Course on Patenting Chemical Innovations." Journal of Chemical Education 98(6): 1974-1981.

Soares, R. and R. Naegelle (2021). "Segregação vertical na área da Química durante a pandemia de Covid-19 no Brasil." Cadernos de Pesquisa 51: e07754-e07754.

Staniscuaski, F., F. Reichert, F. P. Werneck, L. de Oliveira, P. B. Mello-Carpes, R. C. Soletti, C. I. Almeida, E. Zandona, F. K. Ricachenevsky and A. Neumann (2020). "Impact of COVID-19 on academic mothers." Science 368(6492): 724-724.

Valentova, J. V., E. Otta, M. L. Silva and A. G. McElligott (2017). "Underrepresentation of women in the senior levels of Brazilian science." PeerJ 5: e4000.

Zarbin, A. J. and M. M. Oliveira (2013). "Nanoestruturas de carbono (nanotubos, grafeno): Quo Vadis?" Química Nova 36(10): 1533-1539.