Heliyon 6 (2020) e05303

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Research article

Nanotechnology activities: environmental protection regulatory issues data

Luciana Almeida [a,*], Israel Felzenszwalb [b], Mônica Marques [c], Carla Cruz [d]

[a] Science Doctoral Program at the Departament of Post-Graduate in Environment, State University of Rio de Janeiro, Brazil
[b] Departament of Biophysics and Biometrics at the Institute of Biology Roberto Alcantara Gomes, State University of Rio de Janeiro, Brazil
[c] Departament of Organic Chemistry at the Institute of Chemistry, State University of Rio de Janeiro, Brazil
[d] Computacional Sciences Doctoral Program at the Institute of Mathematics and Statistics, State University of Rio de Janeiro, Brazil

ARTICLE INFO

Keywords:
Environmental science
Nanotechnology
Scienciometry
Environmental protection
Regulation
Sustainability

ABSTRACT

Nanotechnology is a fascinating technology that is revolutionizing science and bringing countless benefits to the population. The economic side linked to nanotechnology has grown in recent years, as have the lines of research. However, nanoparticles can be toxic when released into the environment. In this work, a scientometric study was carried out in order to identify and describe scientific research on environmental protection involving nanotechnology with respect to regulatory studies. The research period was from 2003 to 2020, the database selected was Scopus and the software used for the study was Microsoft Excel and VOSviewer. According to specified keywords, the result presented by Scopus was a total of 106 publications. The clustering figures shown by VOSviewer showed that nanotoxicity studies were mostly aimed at protecting human health, to the detriment of environmental protection. Another interesting fact is that toxicity of nanomaterials has been studied from the perspective of risk assessment, including by the regulatory sector.

1. Introduction

In the 21st century, nanotechnology is one of the main transforming technologies, and many industries are being revolutionized with the benefits that this new technology offers. The advancement of nanoscience and nanotechnology is expected to stimulate not only the exploration of new phenomena and new theories, but also lead to an industrial revolution, becoming the new driving force of economic growth in this century [1, 2], teasing a deeper effect on the society of the future than the impact caused by automobiles, airplanes, televisions, and computers in the 20th century [3].

Nanotechnology is an emerging field of research, which explores the use of nanoparticles in the range up to 100 nm (nanometers), or less, conferring better and new qualities to the particles, in relation to their larger size, conventionally employed [1] and making application possibilities are almost endless. Some products that result from nanotechnology include waterproof fabrics, plastics as strong as steel and aluminum, cosmetics whose particles penetrate the skin pores and flying mini robots [4, 5].

Investments in nanoscience and nanotechnology are present in all areas of knowledge and some references even cite a global movement in the nanotechnology market in the order of trillions of dollars, encompassing businesses, bodies and agencies that promote research and development worldwide [6, 7, 8, 9, 10]. In 2020 it is estimated an increase of half a million tons in the global production of nanomaterials developed with specific characteristics for different applications [11].

Despite the significant increase in the use of nanomaterials, little has been discussed about the possible toxic effects for the environment and human health [12]. The same characteristics that make nanoparticles interesting from the point of view of technological application, may be undesirable when they are released to the environment, given the intrinsic characteristics of nanoparticles, such as size, surface area and agglomeration/dispersion capacity, which can facilitate the translocation of these by the environmental compartments and cause, in a cumulative way, damages to the food chain [13]. Experimental studies carried out so far have indicated that several types of nanoparticles may have adverse effects on the embryonic development of invertebrates such as sea urchins, oysters and freshwater snails; of non-mammalian vertebrates (fish and frogs) and of mammals - rats and mice [14]. In view of the nanotechnology scenario, it is essential to adopt specific regulations that ensure the protection of the environment, so that we can benefit from the innovation that nanotechnology brings us without harming the planet.

* Corresponding author.
E-mail address: meioambiente.pesquisa.uerj@gmail.com (L. Almeida).

https://doi.org/10.1016/j.heliyon.2020.e05303
Received 23 June 2020; Received in revised form 14 July 2020; Accepted 15 October 2020

Thus, the objective of the present work was to identify and describe the scientific research available on platforms, which involve nanotechnology and regulatory study in the environmental area.

2. Materials and methods

An exploratory study was carried out, which, as classified by Vanti [15], is called "scientometric study" or "scientometry". Such a study is characterized as a branch of science defined as the study of the measurement and quantification of scientific progress, in which the research is based on scientometric indicators [16].

According to some authors [17], the evaluation of accumulated knowledge is an urgent need for any research sector, since from this knowledge produced it is possible to infer about new areas of investigation, pointing out ways to be followed. In this sense, Soares [18] and Dávila [19] emphasize that the understanding of the state of knowledge on a theme, in a given period, is of great importance for the process of understanding the evolution of science, contributing to the periodic ordering of the set information and results already produced. Thus, it is possible to indicate the possibilities of articulation and integration from different perspectives, which at first were autonomous, as well as enabling the identification of contradictions and the determination of gaps.

The search for published works was carried out in the Web of Science and Scopus research bases, using the keywords: "nanotechnology", "environment" and "legislation".

Microsoft Excel (version 16051.12325.20298.0) and VOSviewer (version 1.6.13.0) were used to analyze the results.

Microsoft Excel was used to organize and catalog the references and produce graphs of the distribution of the number of scientific papers per year, by countries and by areas, from 2003 to 2020.

VOSviewer is a program created by Eck and Waltman [20], which makes it possible to create maps using the mapping and grouping technique.

Clustering is a multivariate statistical technique that aims to divide a sample or population into groups, according to the measure of similarity (or dissimilarity) adopted. This, in turn, calculates the distance of the elements in order to unite them in the same group if they are homogeneous (similar) to each other, and that elements from different groups are heterogeneous with respect to the characteristics [21].

For this work, the distance used will be the Euclidean, as the VOSviewer is based on the same, and it is calculated in such a way that the shorter the distance, the greater the relationship between the nodes [22]. Let v and y be two sample vectors (elements), the Euclidean distance between them is defined by Figure 1 [23]:

That is, the shorter the distance between the words, the more similar they are, thus forming a "cluster" group. It should be noted that the calculation is performed by the automatic program.

Similarity is defined as the strength of association of co-occurrences weighted by the number of times the word appears.

But before calculating the distance, the scores for each occurrence are calculated, which are the weights that each word has, so that the most relevant ones are selected. In the case of similar words, only the word with the highest score in terms of relevance is selected [20].

The results of the research that were provided in the Scopus database were transferred, in CSV Excel format, to the VOSviewer software, which presented the clustering graphs, in the period from 2003 to 2020, in general, and in the periods from 2003 to 2011 and from 2012 to 2020.

$$d(v,y)=\sqrt{\sum_{i=1}^{T}(v_i-y_i)^2}=\sqrt{(v_1-y_1)^2+\ldots+(v_T-y_T)^2}$$

Figure 1. Euclidean distance equation between words.

3. Results and discussion

The Web of Science research database provided a publication result equal to 33 results while in the Scopus database the result was 106 publications. In both bases, the result is equivalent to the total number of publications without including any filter in the research.

The Scopus database was chosen to analyze the results because it provided a larger number of publications.

3.1. Analysis of results

3.1.1. Using excel software

The results of the research in the Scopus database showed that the first publication with the determined keywords ("nanotechnology", "environment" and "legislation") was in 2003, with a total of five publications in the next three years. This number increased from 2006, fluctuating over the years, but maintaining a higher average compared to the years in which the publications started, as shown in Figure 2.

Roco [2] also noted, from 2006, an exponential growth in the development of nanotechnology, including scientific discoveries. The decade of the 2000s instituted the period in the history of the beginning of major developments in nanotechnology, meeting the launch of the National Initiative on Nanotechnology (NNI), in 2000, an important program of research and development (R&D) in nanotechnologies, launched in the United States.

Regarding the types of publication, most are represented by Articles (37.4%), followed by Conference Papers (25.2%) and Reviews (19.6%), as shown in Figure 3.

The results were also analyzed in the light of the distribution of publications by country or territory, as shown in Figure 4.

Figure 4 shows that the United States leads the publications (30 publications), on nanotechnology, environment, and legislation. The first publication in this period was made by that country and addressed the question of the approval of the law in that country to promote research in nanotechnology [24].

India and other European countries (Italy, the Netherlands, and the United Kingdom) also show significant productivity in this area compared to other countries.

Brazilian publications were made up of 2 articles in this period, even if quantitative from Argentina. Colombia, on the other hand, presented a result of only 1 publication. Thus, Brazil is configured as a representative of Latin America, together with Argentina, in research on nanotechnology, environment and legislation.

Regarding the articles published in Brazil, in the research carried out, the first of them was published in 2015 and concerns a regulatory study of several countries in relation to the regulation of nanomaterials, specifically in cosmetic products, which also addressed the environmental theme.

The other article was published in 2016 and addresses the issue of nanoparticle nanosafety and its regulatory aspects.

Figure 5 represents the distribution of publications by continents and shows that Europe leads the total number of publications, followed by North America and Asia, with South America being fourth place. This chart also rectifies the special attention that should be paid in South America, Oceania, Central America and Africa, large areas of the globe with smaller publications of regulatory environmental research related to nanomaterials.

As for the classification of articles by sphere, most were published in the areas of Engineering (22%), followed by Environmental Sciences (10.0%), Materials Science (10.0%) and Social Sciences (8.5%), as shown in Figure 6. It is interesting to note that, despite the keywords refer to the themes of "environment" and "legislation", the Engineering area was the pioneer in the publication of articles, which may suggest that the applicability of publications, even involving such keywords, whether in the application of nanomaterials in Engineering or that Engineering tools are being used to address issues involving the specified keywords.

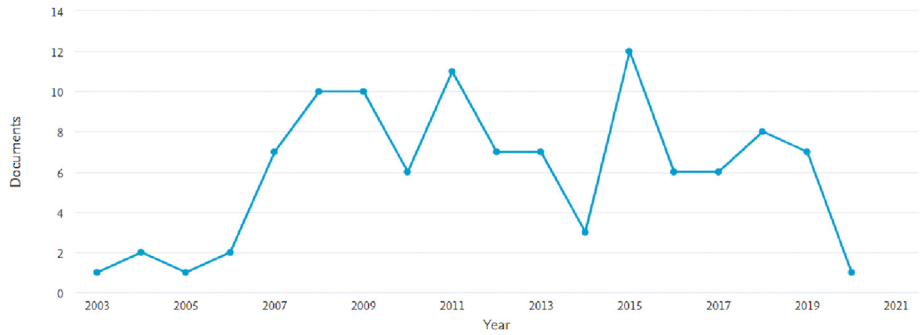

Figure 2. Documents by year.

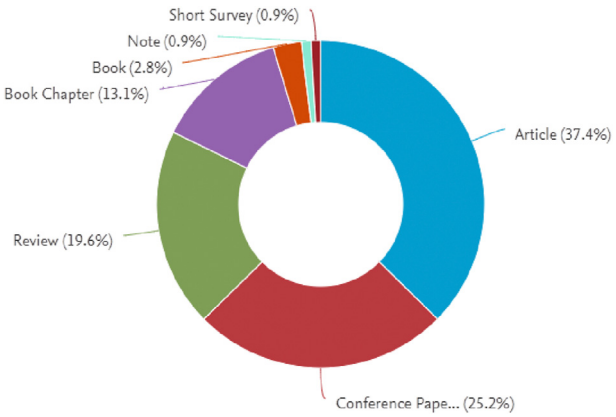

Figure 3. Documents by type.

Another interesting finding was the highlight in the Social Sciences area, representing 8.5% of publications. Through this data it is possible to affirm that importance has been given in these Sciences to a new technology, which is nanotechnology, related to regulatory and environmental aspects, which leads us to understand the interdisciplinarity of Exact and Human Sciences in the problem of this scientific research.

Other Sciences also had significant representation, such as Chemical Engineering, Computer Sciences, Pharmacology and Medicine, areas where nanotechnology is widespread.

Figure 7 shows the number of publications by sponsoring institution. The first place went to the European Commission, which leads the sponsorship on such topics. In second place is the Environmental Protection Agency (United States), tied with the Horizon 2020 Framework Program (European Commission Program), the National Science Foundation (United States) and the Environment Research Council (United Kingdom).

This analysis is in accordance with Figure 5, which highlights the European continent as the majority in number of publications and secondly North America.

Notable consideration can be given by the fact that the pioneer organizations in sponsoring these researches, with the exception of the Environmental Protection Agency, are research institutions that operate in several fields of activity and are not exclusively focused on the environmental area.

3.1.2. *Analysis of citations and use of excel software*

As already reported in another topic, the result of the research was 106 publications in the Scopus database. These publications had an average of 15.78 citations. An analysis was made of publications that had a number equal to or greater than 15 citations, in order to study the theme of the main research cited. As a result, 26 publications were selected, and the distribution of the studied theme is shown in Figure 8.

It is expected that the publications most cited are those that have had the greatest impact and scientific recognition and are issues that contributed most to the central theme of the research.

Although all publications address the environmental issue, regulatory issues and nanotechnology, in 26 publications analyzed, 13 had as their

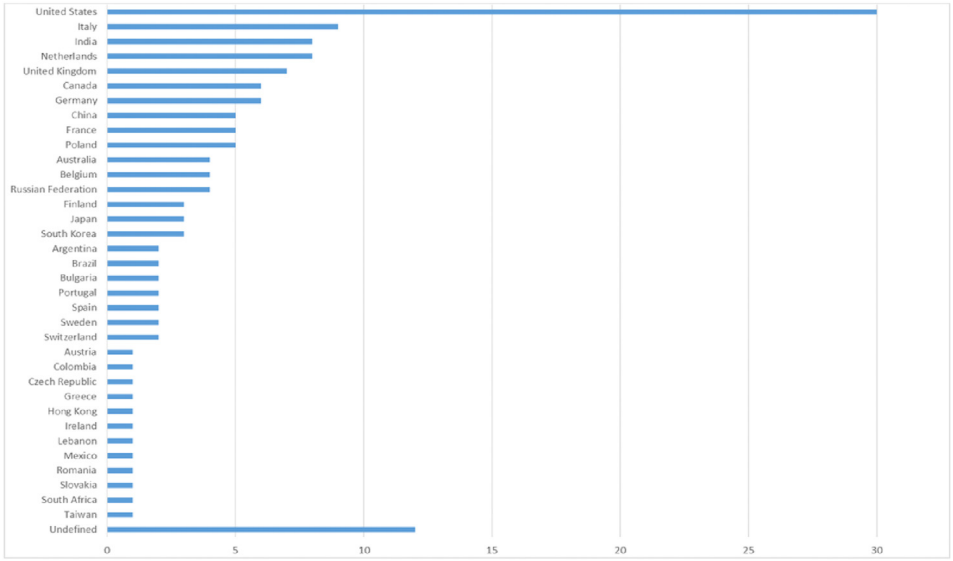

Figure 4. Documents by country or territory.

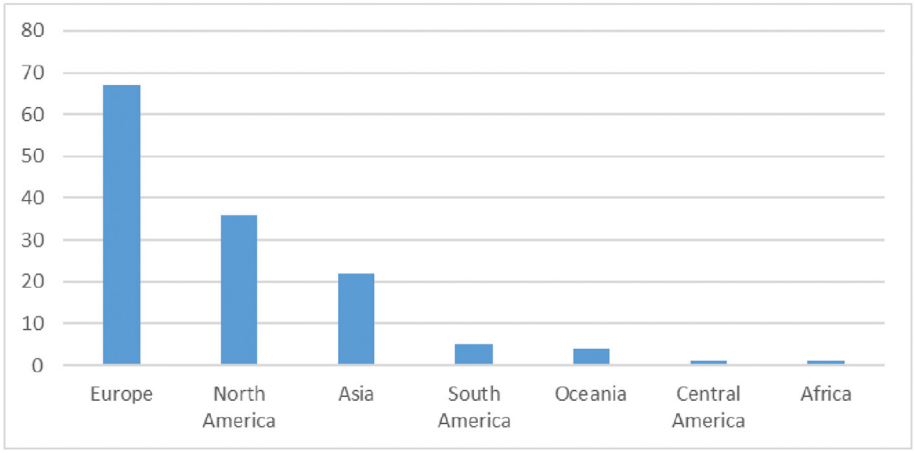

Figure 5. Documents by continent.

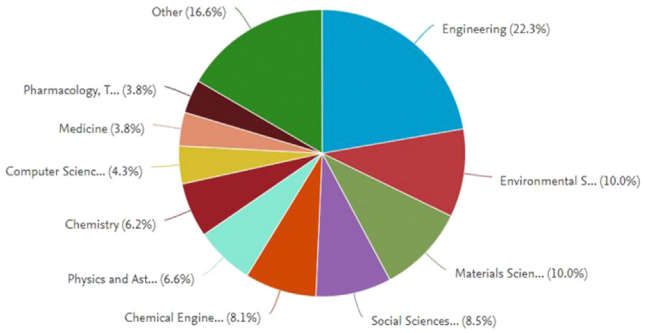

Figure 6. Documents by subject area.

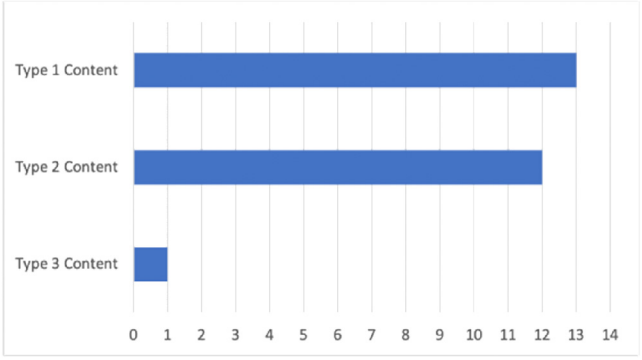

Figure 8. Distribution of the content of the most cited publications (Type 1 content: Practical use of nanomaterials; Type 2 content: Regulatory issues, tools, and risk assessment models; Type 3 content: Potential for toxicity, waste, and environmental management of nanoparticles).

main focus the study of some practical use of nanotechnology, such as in the area of food and agriculture, in eco-design of electronic products, in remediation of environmental contaminants, in the textile industry, in electrodes to minimize gas emissions, in stem cells and various uses in technology, like shown in Type 1 content. That is, half of the works with the highest citation rate had repercussions in research on the development of new products involving nanotechnology.

Another large portion (Type 2 content), with a number of publications equal to 12, had the main focus in fact on the regulatory issues of nanomaterials - from several countries and regions, which we can mention the European Union, United States, Asia and Brazil, tools and risk assessment models that were being studied by researchers and regulators, such as product life cycle. These works address both environmental issues and human toxicity for regulatory purposes, but human toxicity is more prominent.

Finally, we can cite Type 3 content, which presented only one article, but with 359 citations, a record number among citations in publications. This article, within the search carried out, published in 2009, was the first to exclusively address the issue of environmental management of nanoparticles in order to present technical and accurate information about nanomaterials, as intrinsic characteristics of these materials (such as dimension, morphology, composition, uniformity and agglomeration status) and also the toxicity of the residues generated by these products, in an impartial way to the regulators. The authors of this publication warn of a possible creation of a "new generation of pollutants" caused by the use of nanoparticles and put society to reflect on nanotechnology in

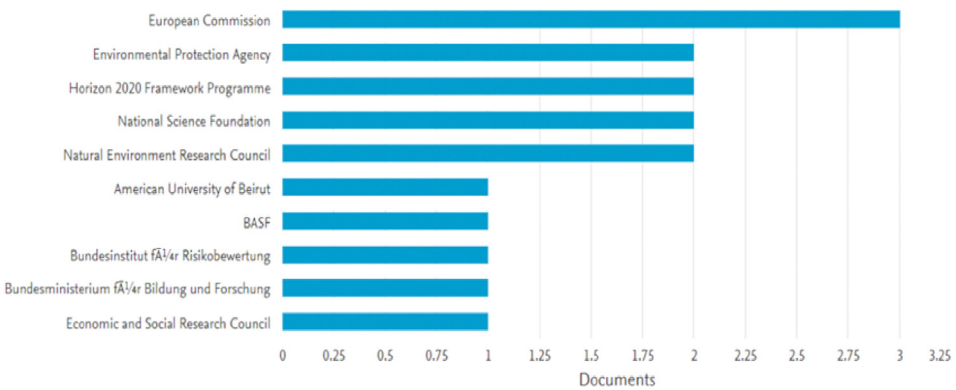

Figure 7. Documents by funding sponsor.

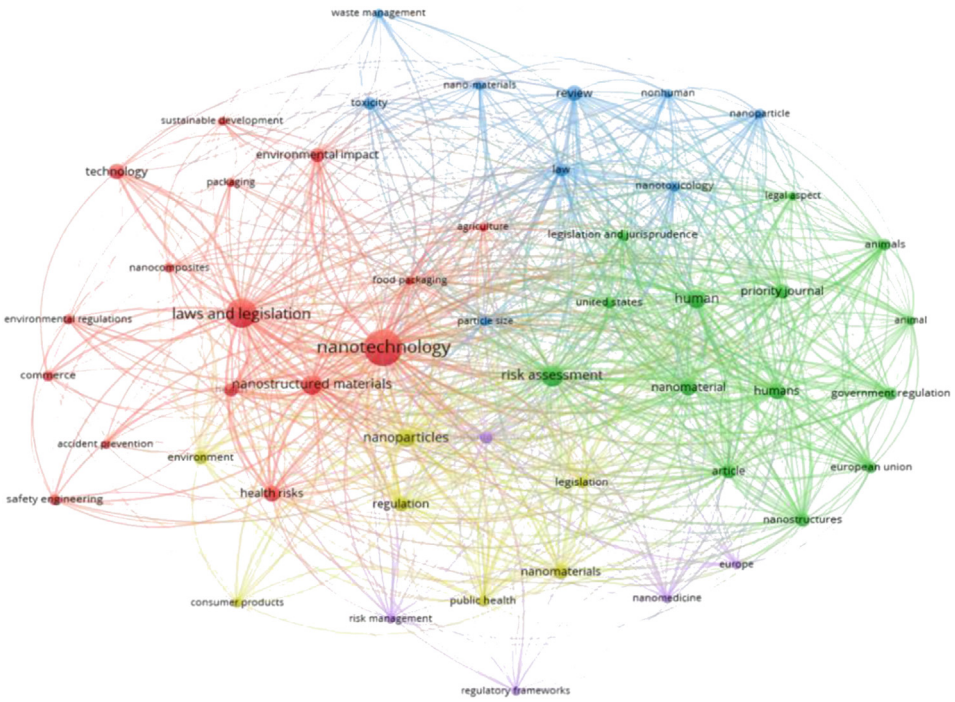

Figure 9. Word grouping from 2003 to 2020.

the light of the Amara's law: "We tend to overestimate the effect of a technology in short term and to underestimate the long term effect ".

At the beginning of the dissemination of nanotechnology and where several actors are beginning to act in the face of new technology, it is possible that this article, of a purely technical and impartial character, published by university researchers, has gained a lot of value and has had considerable scientific repercussion, compared to other citations.

Considering the countries in relation to the publication of articles, the USA leads the publication of papers both of those classified as Type 1 (30%) and Type 2 (25%).

The ranking of the other countries that published in Type 1, stands out China (15%), United Kingdom and Australia (each representing 10%); South Korea, Mexico, Colombia, India, Poland, Japan and the Netherlands (each with a 5% share).

The ranking of the other countries that published in Type 2, the Netherlands and Italy stand out (each representing 12.5%); Spain, Hong Kong, Canada, Germany, Bulgaria, Brazil, Ireland and the United Kingdom (each with a share of 6.25%).

The group classified as Type 3 is represented only by Poland.

These results are in accordance with Figure 4, in which the USA leads the publication of articles and the vast majority of countries cited in this approach appear in the top 10 of the ranking in Figure 4.

3.1.3. Using the VOSviewer software

The result of the research provided in the Scopus database in CVS Excel format was transferred to the VOSviewer software. The first result presented was the cluster in the period from 2003 to 2020, no type of filter was used for the analysis. That is, the entire base of results in the research was considered, including year, type of publication, authors and areas. The minimum number of occurrences of the keywords was specified to be 5 words. With these predetermined specifications, the software identified 51 keywords, which are grouped as shown in Figure 9, and the density of co-occurrence between words as shown in Figure 10.

As shown in Figure 9, the keywords used in the search (or similar terms) are interrelated in all the groupings shown by the software (each color shows a certain group or "cluster"), showing the interrelationship between the keywords.

Another important aspect is that, as nations, only "United States" and "Europe" appear in the cluster in Figure 9, which shows that these nations are among those that most publish and are concerned with the aspects of this research. This result is compatible with the results shown in Figure 4, which shows that the United States is a pioneer country in the publication of scientific papers on the research topic.

Figure 10 shows that the words with the highest density in the search were "nanotechnology" and "laws and legislation". The words "environment" and "environmental impact" were not highlighted in this co-occurrence analysis, showing that they were not a major topic in the research aspects, as well as the word "garbage management", which appeared isolated, with low density and distant from the main terms ("laws and legislation" and "nanotechnology").

Analyzing still Figure 10, it is observed that the words "human" and "health risks" had a higher co-occurrence compared to the environment, showing that comparatively, the aspects related to human health in the use of nanomaterials had greater prominence when compared to environmental impacts caused by nanoparticles.

The result shown in Figure 10, of nanotechnology is closely related to the laws and legislation is in line with research already carried out. Innovation is usually accompanied by concern by regulators, whose mission is to protect the population's health and environmental protection [25, 26]. As of 2003, nanotechnology research became official [24]. As a result, the number of studies aimed at regulating nanotechnology has increased since then.

In order to identify the evolution of searches over time, for the terms searched, the figures of density of the co-occurrence between words were elaborated in two periods: 2003 to 2011 (Figure 11) and 2012 to 2020 (Figure 12). In the first period (2003–2011), 49 published works were identified. In the second (2012–2020) a number of 57 works. The results are shown below.

As shown in Figure 11, the words with the highest density in the period 2003–2011 were "nanotechnology" and "laws and legislation", both of which are closely related. In this period, the words "health" and

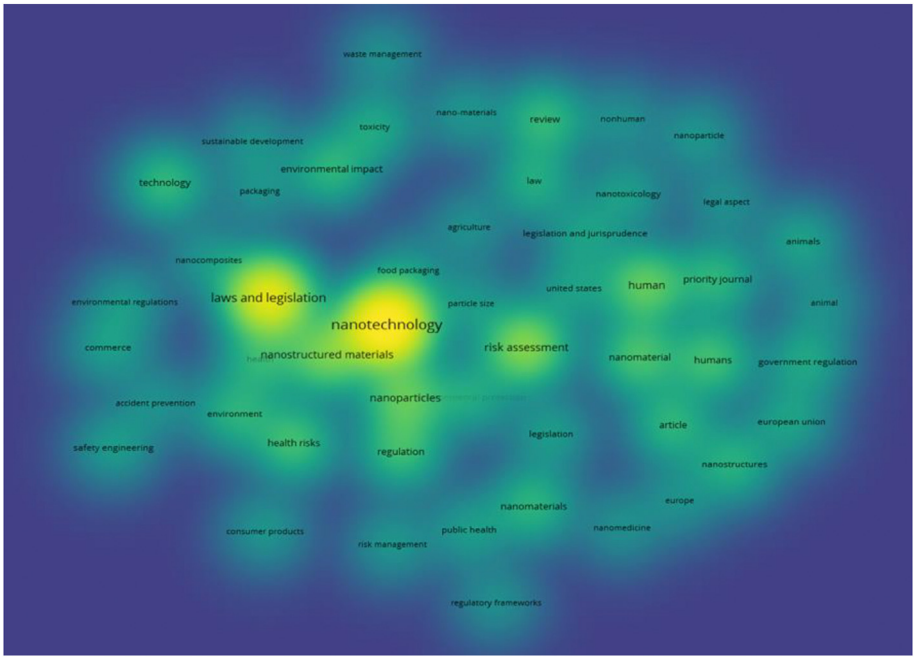

Figure 10. Density of co-occurrence between words in the period 2003–2020.

"health risks" also appear closely related to "nanotechnology" and "laws and legislation". The words "environment" and "environmental impact" are also related, being very closely to each other, but these last two are more distant from the words "nanotechnology" and "laws and legislation" in comparison to "health" and "health risks". This result is in accordance with the conclusions of Figure 10. That is, during this period, the greatest concern in relation to nanotechnology was in relation to human health itself and not in relation to the protection of the environment.

Other high-density words in the period shown in Figure 11 are "technology", "toxicity" and "nanotoxicity", which rectifies the concern of the new technology, which is nanotechnology, in relation to the damage it can cause to human health. Thus, studies that aim to evaluate the toxicity of nanoparticles prevail.

In the period from 2012 to 2020, 57 published works were identified, a number reasonably comparable to the previous period, which allows us to make a comparative analysis between the periods in relation to the number of publications.

As shown in Figure 12, it is possible to verify that new words were highlighted in the period, for example, the words "food packaging", "agriculture" and "packaging" appeared, terms that had not been highlighted previously. That is, new areas applicable to nanotechnology began to be studied from that period.

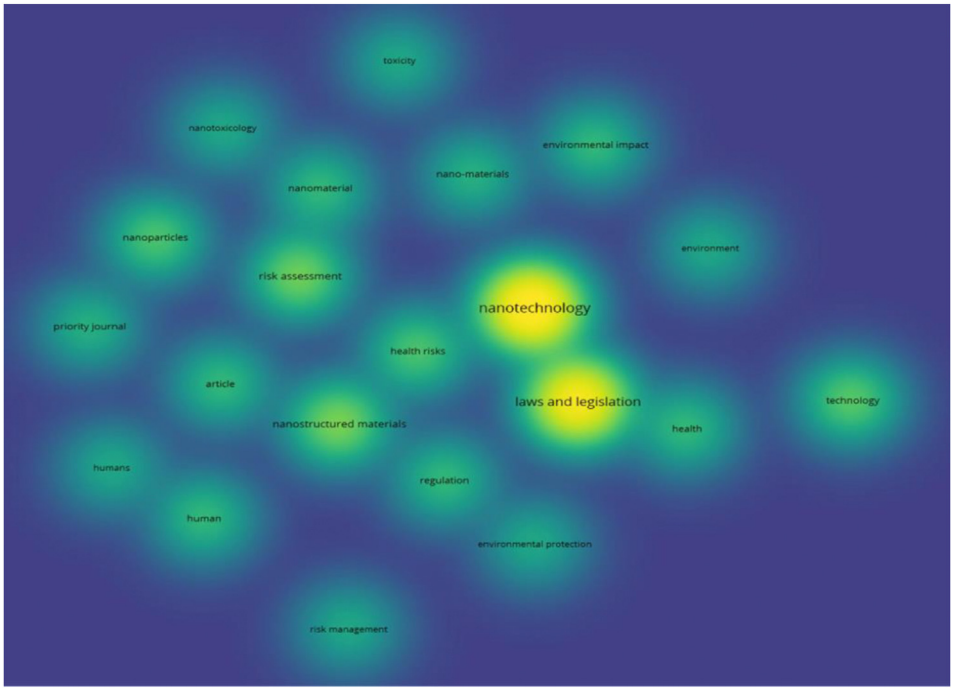

Figure 11. Density of co-occurrence between words in the period 2003–2011.

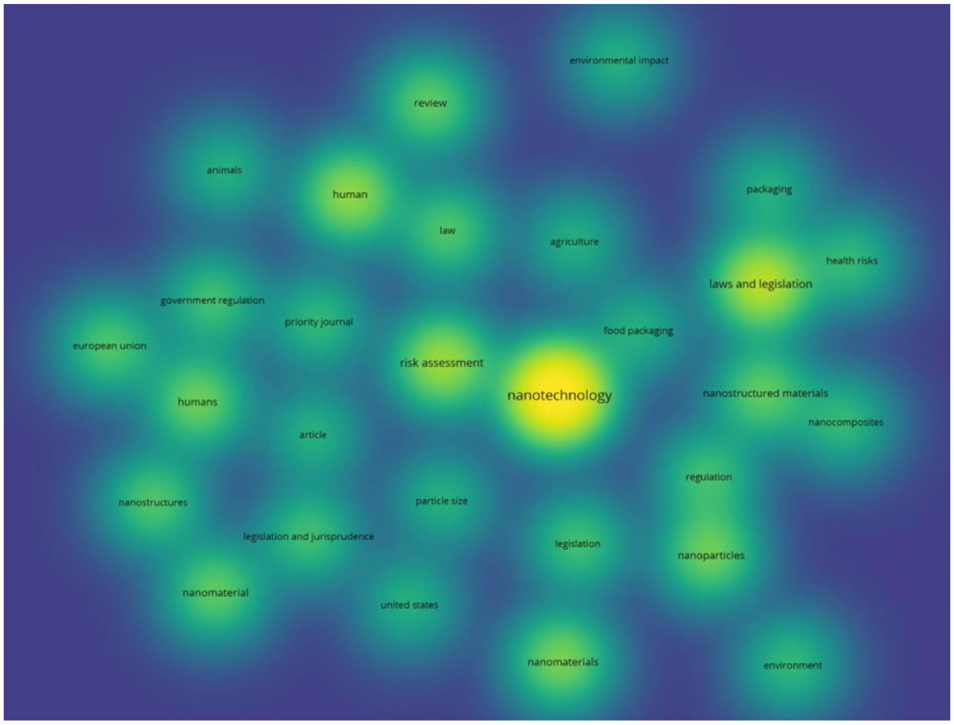

Figure 12. Density of co-occurrence between words in the period 2012–2020.

Another interesting finding in Figure 12 is that the word “nanotechnology” remains in prominent density but is now closely related to the term “risk assessment” and no longer “laws and legislation”. That is, during this period, the risk assessment of nanotechnology was highlighted in published works. According to Trump et al. [27], the risk assessment of nanomaterials is a challenge for government agencies, which have started to use risk assessment tools to evaluate nanomaterials and make decisions related to these products, which explains and justifies this result.

"Laws and legislation" now appear as a new cluster and the center of discussion of the words "food packaging", "packaging", "health risks" and "nanostructured materials". According to Amoabediny et al. [28], if on the one hand nanotechnologies can contribute to food security, there is, on the other hand, a concern about the toxicity of nanoparticles. Because they are very small particles, there is a risk of crossing the cells or passing directly to the lungs, falling into the bloodstream, and reaching all the organs of the body.

It can be said that, after the application of a new technology to a certain area, the regulation is shown to be closely related, as previously discussed. This fact can also be seen in Figure 11, when the first works involving nanotechnology appeared.

The words “environment” and “environmental impact” also appear in Figure 12, but in the same way as in Figure 11. That is, without being the center of the discussions. In Figure 11, the words "environment" and "environmental impact" are close, showing the proximity of the studied themes. In Figure 12, the word "environmental impact" is far from "environment", which is close to "nanomaterials" and "nanoparticles". Thus, it can be said that in this period, studies on the application of nanotechnology in environmental issues, such as soil remediation and decontamination of other environmental matrices, and not studies on the environmental impact of nanoparticles, were highlighted.

This finding has already been confirmed by the scientific literature, which shows that the application of various types of engineered nanomaterials has gained attention in recent years [29, 30, 31]. In this sense, several metallic and non-metallic compounds were synthesized and used in order to remove various environmental contaminants [32, 33, 34].

Regarding nations, the only terms that were highlighted in the figures were "European Union" and "United States", which had density highlighted in Figure 12. This shows the lack of studies in several countries.

In general, these results show a lack of specific regulatory studies applied to nanotechnology regarding environmental impacts and protection.

4. Conclusions

This article provides a brief contextualization of environmental protection regulatory issues related to nanomaterials with respect to scientific research.

Although numerous studies have already identified the negative impacts on the environment that nanoparticles can cause, the results show that studies related to the toxicity and use of nanomaterials were mostly directed towards studies aimed at human protection.

A paradigm shift was also noted. From 2003 to 2011, the focus of studies related to nanomaterials was focused on laws and regulations. In the period from 2012 to 2020, studies focused on the risk assessment of nanomaterials, including in the regulatory sphere.

The country that published the most scientific papers in the period studied was the USA and continentally, Europe was the pioneer in the publication.

The results consolidate the importance of regulatory studies on the environmental protection of nanomaterials on a global theme.

Declarations

Author contribution statement

Luciana dos Santos Almeida, Israel Felzenszwalb, Monica Marques: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Carla Cruz: Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Funding statement

This work was supported by PPGMA (Postgraduate Program in Environment) of UERJ (State University of Rio de Janeiro).

Competing interest statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

References

[1] K. Shameli, et al., Green biosynthesis of silver nanoparticles using Callicarpa maingayi stem bark extraction, Molecules 17 (7) (2012) 8506–8517.
[2] M.C. Roco, From vision to the implementation of the U.S. National nanotechnology initiative, J. Nanoparticle Res. 3 (1) (2001) 5–11.
[3] P.L. Gai, R. Roper, M.G. White, Recent advances in nanocatalysis research, Curr. Opin. Solid State Mater. Sci. 6 (5) (2002) 401–406.
[4] W.L. Barth, Nanotechnology, Porto Alegre Quarterly Magazine 36 (153) (2006) 669–695.
[5] M.R. Piscopo, et al., The Brazilian Nanotechnology Sector: Opportunities and Challenges. XXXVII ANPAD Meeting, Rio de Janeiro/RJ, September 2013, pp. 7–11.
[6] F. Galembeck, M.M. Rippel, Polymeric nanocomposites and nanopharmaceuticals: facts, opportunities and strategies, Strategic Partnerships 18 (43) (2004) 41–60.
[7] BCC Research, Nanotechnology: a Realistic Market Assessment, 2014. Available: https://www.reportlinker.com/p096617/Nanotechnology-A-Realistic-Market-Assessment.html. Acess: 23 april 2019.
[8] BCC Research, The Maturing Nanotechnology Market: Product and Applications, 2016. Available: https://www.bccresearch.com/market-research/nanotechnology/nanotechnology-market-products-applications-report.html. Acess: 23 april 2019.
[9] INFORCHANNEL, Trends: Nanotechnology Makes the Industry Competitive, Says ABDI, 2018. Available: https://inforchannel.com.br/2018/05/11/nanotecnologia-torna-a-industria-competitiva-diz-abdi. Acess: 23 april 2019.
[10] X. Liu, et al., Trends for nanotechnology development in China, Russia, and India, J. Nanoparticle Res. 11 (2009) 1845–1866.
[11] T.L. Rocha, et al., Ecotoxicological impact of engineered nanomaterials in bivalve molluscs: na overview, Mar. Environ. Res. 111 (2015) 74–88.
[12] L.P.S. Oliveira, M.E. Marinho, E.O. Fumagali, Nanowastes risks to human health and the environment: dialogues between the precautionary principle and the risk society, Iberoamerican Magazine of Philosophy, Politics and Humanities 17 (33) (2015) 183–209.
[13] F.H. Quina, Nanotechnology and the environment: perspectives and risks, New Chemistry 27 (6) (2004) 1028–1029.
[14] I.F. Delgado, F.J.R. Paumgartten, Current challenges of toxicology research: assessment of the toxicity of manufactured nanomaterials for development, Health Surveillance under debate 1 (4) (2013) 11–24.
[15] N.A.P. Vanti, From bibliometrics to webmetry: a conceptual exploration of the mechanisms used to measure the registration of information and the diffusion of knowledge, Inf. Sci. 31 (2) (2002) 152–162.
[16] M.R. Parra, R.X. Coutinho, E.F.C. Pessano, A brief look at scientometrics: origin, evolution, trends and their contribution to science education, Context & Education Magazine 34 (107) (2019) 126–141.
[17] P.M.M. Teixeira, J. Megid Neto, Investigating educational research, A study focusing on dissertations and theses on the teaching of biology in Brazil, Science Teaching Investigations 11 (2) (2006) 261–282.
[18] M.B. Soares, Literacy in Brazil: the state of knowledge, Inep, Reduc 157 (1989).
[19] E.S. Dávila, Analysis of Dissertations and Theses of PPG's in the Área of Science and Mathematics Teaching in RS – 2000 to 2011. 62 F. Dissertation (Postgraduate Program in Science Education), Federal University of Santa Maria, 2012.
[20] N.J. Eck, L. Waltman, Software survey: VOSviewer, a computer program for bibliometric mapping, Scientometrics 84 (2) (2010) 523–538.
[21] S.A. Mingoti, Data Analysis Using Multivariate Statistics Methods: an Applied Approach, 2 ed., Belo Horizonte, UFMG, 2013.
[22] N.J. Van Eck, L. Waltman, Visualizing bibliometric networks, in: Y. Ding, R. Rousseau, D. Wolfram (Eds.), Measuring Scholarly Impact: Methods and Practice, Springer, 2014, pp. 285–320.
[23] R.A. Johnson, D.W. Wichern, Applied Multivariate Statistical Analysis, 6 ed., Pearson Pratice Hall, New Jersey, 2007.
[24] D. Carnevale, House passes bill on nanotechnology research, Chron. High Educ. 49 (37) (2003) A30.
[25] M.G. Wacker, A. Proykova, G.M.L. Santos, Review – dealing with nanosafety around the globe – regulation vs. innovation, Int. J. Pharm. 509 (2016) 95–106.
[26] L.G. Soeteman-Hernández, et al., Perspective on how regulators can keep pace with innovation: outcomes of a European Regulatory Preparedness Workshop on nanomaterials and nano-enable products, NanoImpact 14 (2019) article number 100166.
[27] B.D. Trump, et al., Risk associated with engineered nanomaterials: different tools for different ways to govern, Nano Today 21 (2018) 9–13.
[28] H. Amoabediny, et al., Guidelines for safe handling, use and disposal of nanoparticles, J. Phys. Conf. 170 (1) (2009) 1–12.
[29] T. Yao, et al., Preparation of reduced graphene oxide nanosheet/FexOy/nitrogen-doped carbon layer aerogel as photo-Fenton catalyst with enhanced degradation activity and reusability, J. Hazard Mater. 362 (2019) 62–71.
[30] M.B. Tahir, M. Sagir, K. Shahzad, Removal of acetylsalicylate and methyl-theobromine from aqueous environment using nano-photocatalyst WO3-TiO2@ g-C3N4 composite, J. Hazard Mater. 363 (2019) 205–213.
[31] S.T. Khan, A. Malik, Engineered nanomaterials for water decontamination and purification: from lab to products, J. Hazard Mater. 363 (2019) 295–308.
[32] J. Xu, et al., A review of functionalized carbon nanotubes and graphene for heavy metal adsorption from water: preparation, application, and mechanism, Chemosphere 195 (2018) 351–364.
[33] M. Kamali, M.E. Costa, I. Capela, in: Shahid-ul-Islam (Ed.), Nitrate Removal and Nitrogen Sequestration from Polluted Waters Using Zero-Valent Iron Nanoparticles Synthesized under Ultrasonic Irradiation. Advanced Materials for Wastewater Treatment, John Wiley & Sons, Inc., Hoboken, NJ, USA, 2017.
[34] M. Khalaj, et al., Copper-based nanomaterials for environmental decontamination – an overview on technical and toxicological aspects, Ecotoxicol. Environ. Saf. 148 (2018) 813–824.